PROJECT CHINA STONE

Subsidence Report

A

GORDON GEOTECHNIQUES

GORDON GEOTECHNIQUES PTY LTD
ACN 127 420 839

SUBSIDENCE PREDICTION REPORT FOR PROJECT CHINA STONE

Prepared for Hansen Bailey
On behalf of MacMines Austasia Pty Ltd

OCTOBER 2014

262 Sunrise Drive, OCEAN VIEW, QLD 4521
Mobile: 0428 186 255
Ph/Fax: 07 3425 3720
Email: ggpl@hotkey.net.au

TABLE OF CONTENTS

List of Figures

List of Tables

List of Abbreviations

ASL - Above Sea Level
GGPL - Gordon Geotechniques Pty Ltd
LIDAR - Light Detection and Ranging or Laser Imaging, Detection and Ranging
LOMS - Limit of Measurable Subsidence

Mtpa	- Million Tonnes per Annum
ROM	- Run of Mine
SDPS	- Surface Deformation Prediction System
S_{max}	- Maximum Subsidence

1 INTRODUCTION

1.1 Background

Gordon Geotechniques Pty Ltd (GGPL) was commissioned by Hansen Bailey on behalf of MacMines Austasia Pty Ltd (the proponent) to complete a subsidence assessment as part of the Environmental Impact Statement (EIS) for Project China Stone (the project).

1.2 Project Description

The project involves the construction and operation of a large-scale coal mine on a greenfield site in Central Queensland. The project site (the area that will ultimately form the mining leases for the project) is remote, being located approximately 270 km south of Townsville and 300 km west of Mackay at the northern end of the Galilee Basin **(Figure 1**).

Figure 1. Project Location.

The closest townships are Charters Towers, approximately 285 km by road to the north, and Clermont, approximately 260 km by road to the south-east. The project site comprises approximately 20,000 ha of well vegetated land, with low-lying scrub in the south and east and a densely vegetated ridgeline, known as 'Darkies Range', running north to south through the western portion of the site.

The mine will produce up to approximately 55 million tonnes per annum (Mtpa) of Run of Mine (ROM) thermal coal. Coal will be mined using both open cut and underground mining methods (**Figure 2**). Open cut mining operations will involve multiple draglines and truck and shovel pre-stripping. Underground mining will involve up to three operating longwalls. Coal will be washed and processed on site and product coal will be transported from site by rail. It is anticipated that mine construction will commence in 2016 and the mine life will be in the order of 50 years.

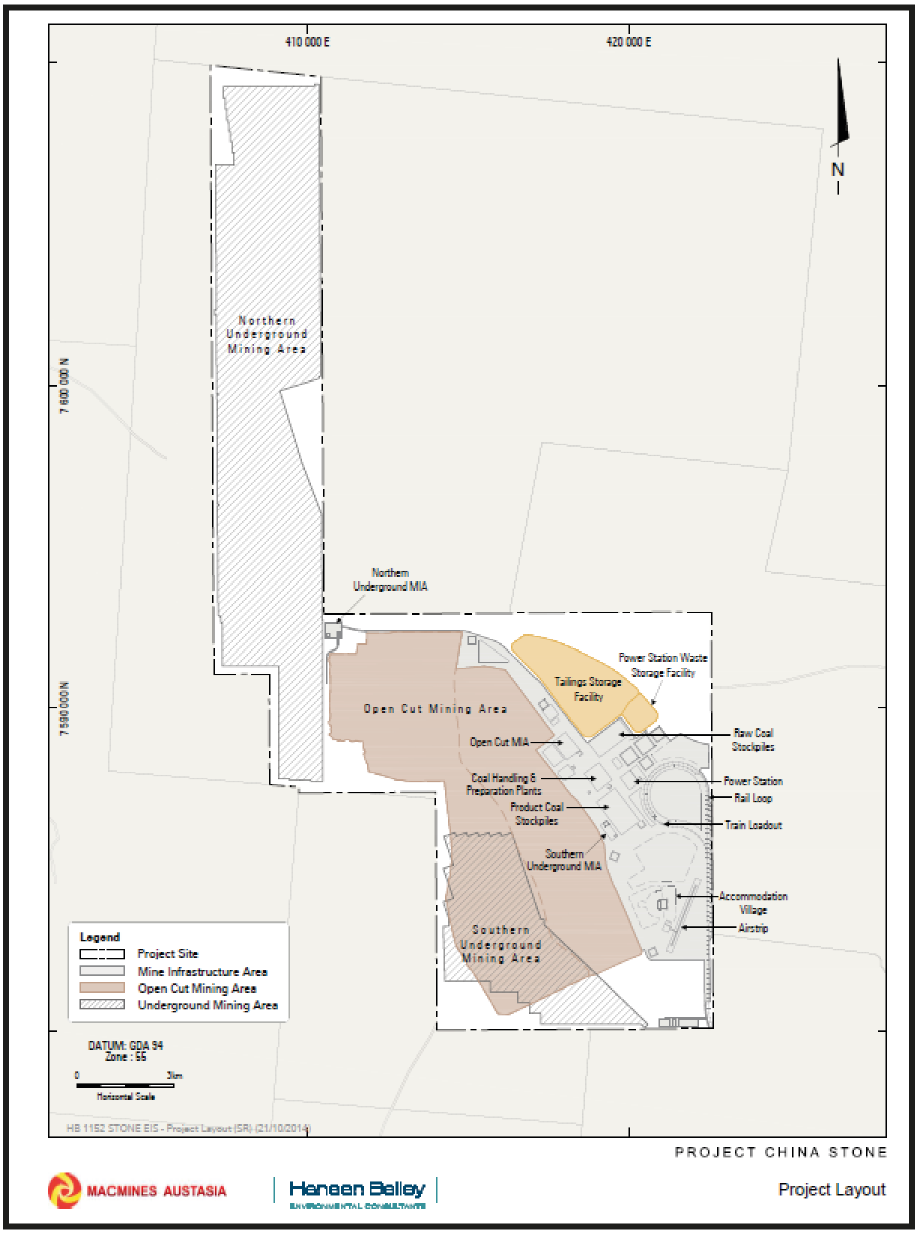

Figure 2. Project Layout.

The majority of the mine infrastructure will be located in the eastern portion of the project site (**Figure 2**). Infrastructure will include coal handling and preparation plants (CHPPs), stockpiles, conveyors, rail loop and train loading facilities, workshops, dams, tailings storage facility (TSF) and a power station. A workforce accommodation village and private airstrip will also be located in the eastern part of the project site.

1.3 Longwall Mining Method and Layout

The project involves establishing up to three longwall operations in the Northern and Southern Underground Mining Areas (**Figure 3**). The Southern Underground will carry out longwall mining in the C Seam. The majority of the Southern Underground is located beneath the open cut mine (**Figure 2**). The Northern Underground will involve longwall mining in both the A Seam and D Seam.

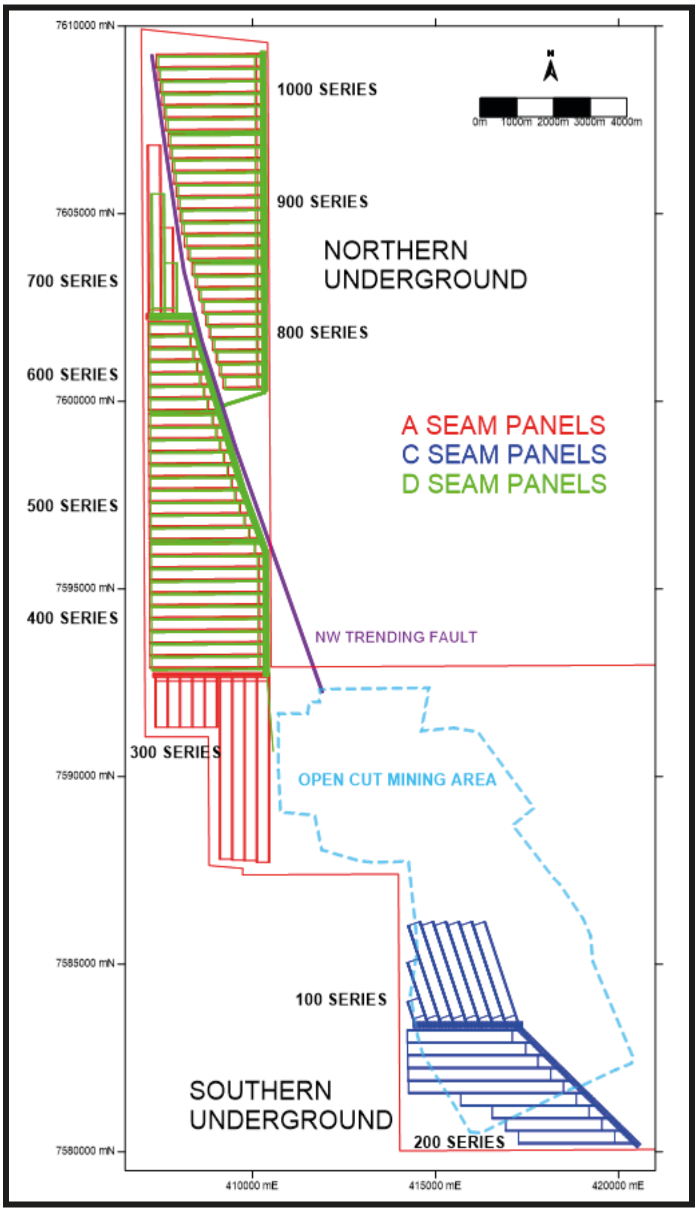

Figure 3. Underground Mine Plan.

The Northern Underground is located beneath Darkies Range in the northern section of the project site (**Figure 2 and Figure 4**).

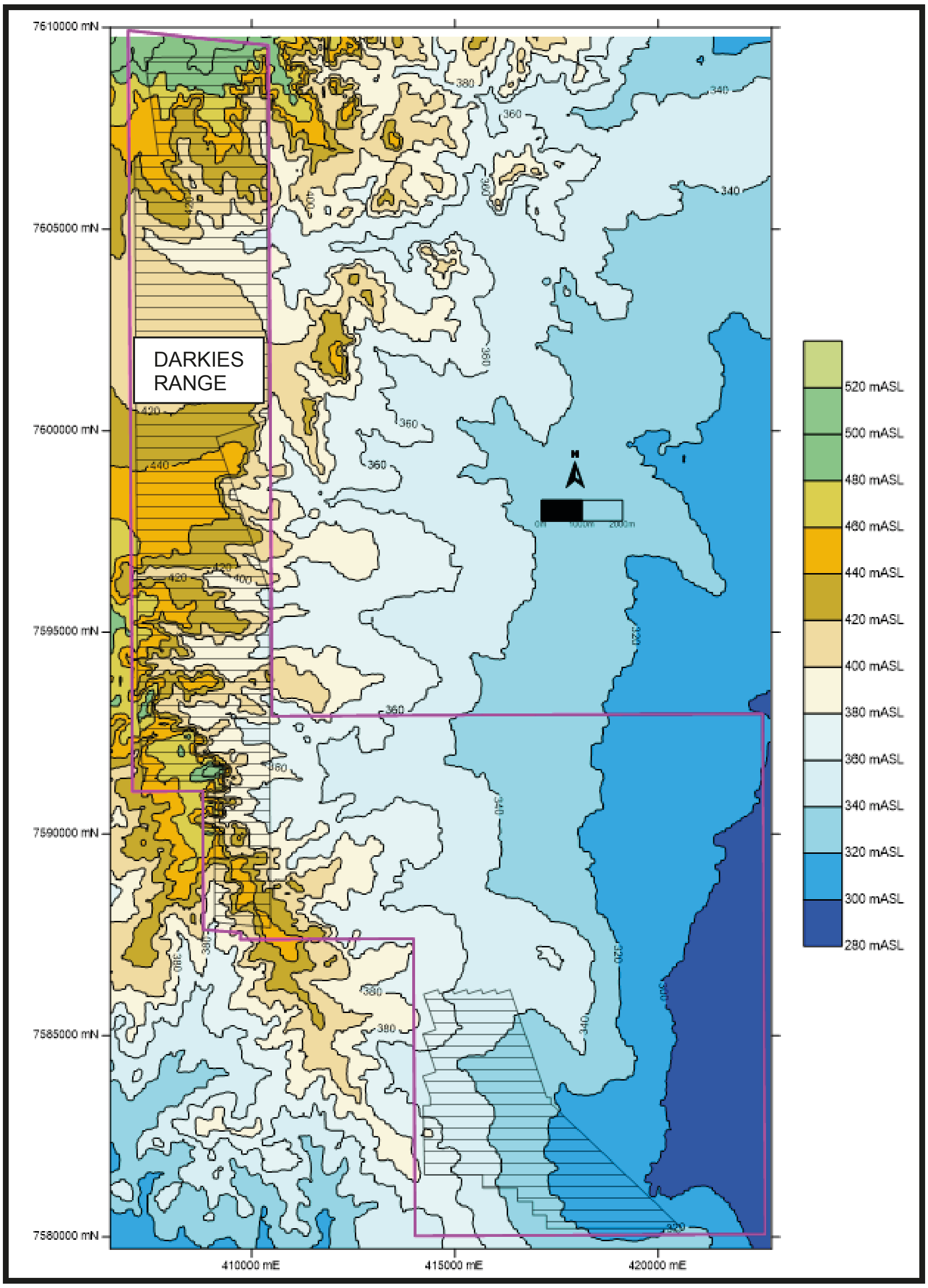

Figure 4. Surface Contours (m ASL).

The layout of the A and D Seam longwall mines is constrained by the proposed lease boundary, as well as the NW trending geological fault that has been interpreted through the northern part of the Northern Underground area (**Figure 3**). The mine schedule indicates that the underlying D Seam will be extracted prior to the A Seam.

Seventeen longwalls panels are also planned in the C Seam longwall mine in the Southern Underground. The northern 100 Series C Seam panels are planned to be extracted before the overlying seams are removed by the open cut operation (**Figure 3**).

Longwalling in the D Seam is planned to finish approximately 27 years after underground roadway development starts. The mining schedule indicates an approximate time lag of 10-15 years between mining in the lower D Seam panels and extraction of the overlying A Seam panels, allowing 5 to 10 years for consolidation of the underlying goaf.

The longwall panels in the A, C and D Seams are designed at 300 m wide (centre dimension) with two heading gateroads (**Figure 3**). Chain pillar widths are 35 m (centre dimension), irrespective of the depth of cover.

1.4 Scope of Work

This assessment includes the development of subsidence predictions and an assessment of subsidence effects for the proposed longwall mining operations in the Northern and Southern Undergrounds (**Figure 2**). The specific scope of work included:

- A four day site visit to inspect the surface area to be subsided and identify any surface features potentially sensitive to subsidence effects.
- Description of the site geology and mine plan as they relate to subsidence predictions.
- Detailed description and justification of the subsidence prediction methodology and any associated limitations.
- Subsidence modelling using the influence functions methods as implemented in the SDPS subsidence program[1] to visualize the resulting subsidence bowl of the longwall extraction and produce surface subsidence contours.
- Description of the predicted subsidence effects including:
  - The magnitude and nature of the subsidence predictions including vertical subsidence, strains and tilts.
  - The nature and extent of predicted surface cracking (range and maximum surface width and depth).
  - The nature and extent of subsurface strata cracking (height of continuous and discontinuous cracking above the mine workings), including comparisons with experience from other similar longwall mines.
  - Potential for hydraulic connectivity to the surface due to subsurface cracking.
  - Potential effects on surface geological features including subsidence and cracking.

1.5 Report Structure

Section 1 of this report introduces the project, including the proposed longwall mining layout and geology of the project site.

[1] www.carlsonsw.com

Section 2 details the geology, stratigraphy, depth of cover and coal seam and interburden thickness.

Sections 3, 4 and 5 describe subsidence methodology, predictions and potential subsidence effects from the project, respectively.

2 ENGINEERING GEOLOGY

2.1 Geological Data

The proposed longwall mining area is covered by closely spaced exploration drilling, as shown in **Figure 5**. These surface drill holes record the geological sequence of the overburden and coal seams.

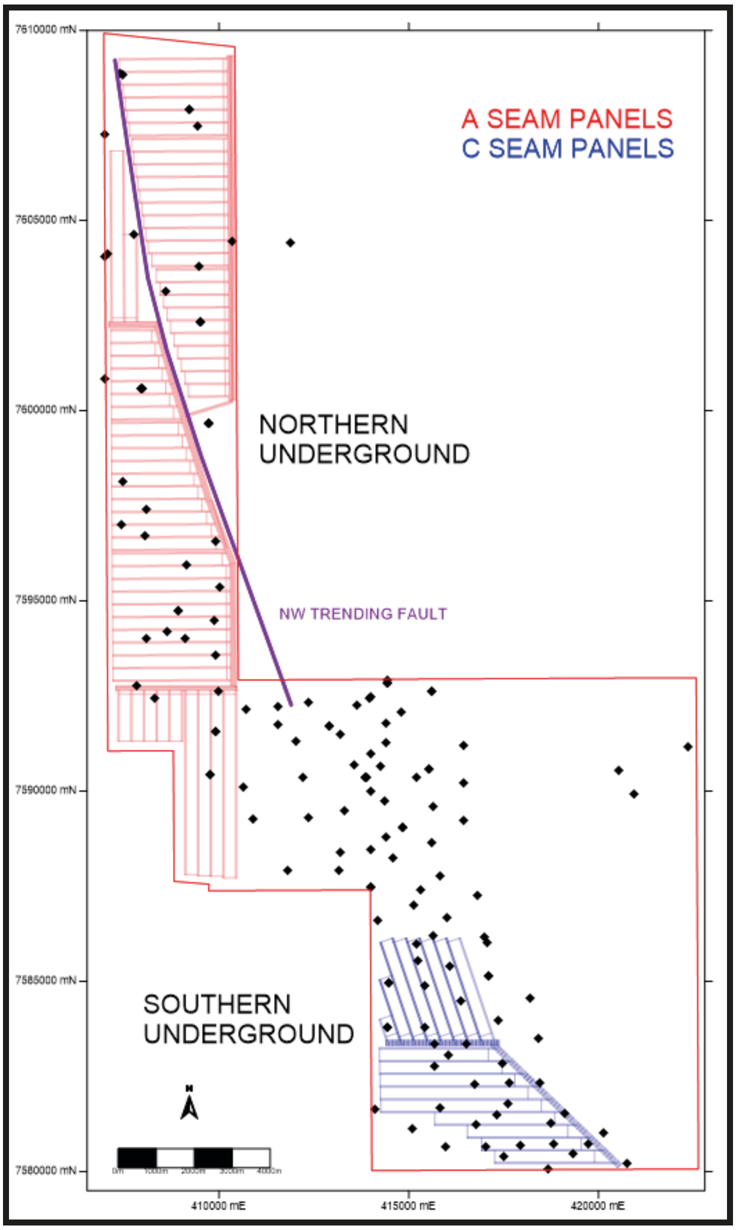

Figure 5. Borehole Location Plan.

In the majority of drill holes, geophysical logs are also available and provide additional data on the rock and coal seam properties. This density of data provides a high level of confidence in the geological variables used as input into the subsidence models in the proposed mining areas.

2.2 Stratigraphy

In the project site, the coal seams are part of the Betts Creek Beds (**Figure 6**). The target seams for longwall mining are the A, C and D Seams. The sediments between the target coal seams typically consist of interbedded sandstones, siltstones and mudstones and minor coal seams.

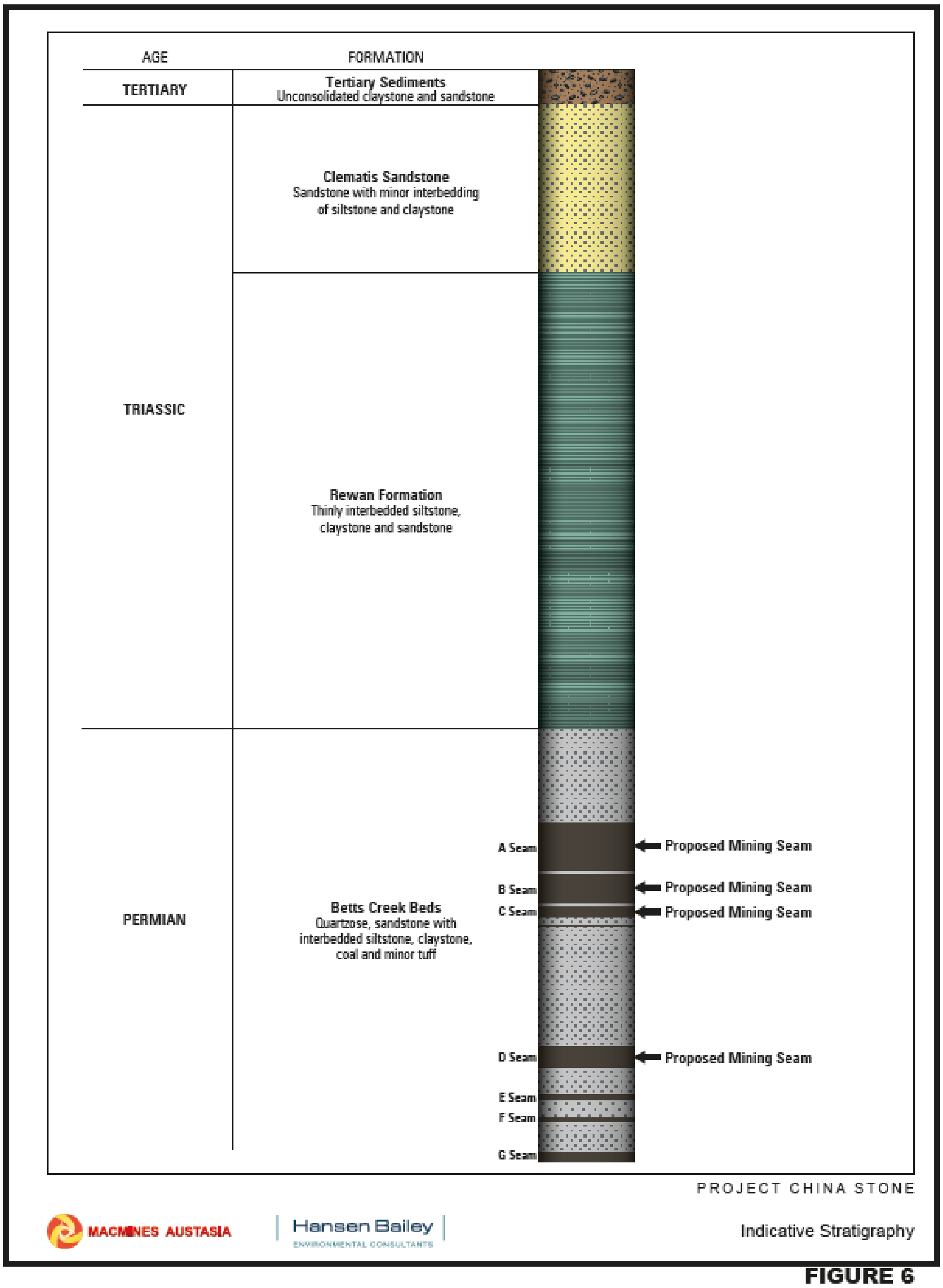

Figure 6. Indicative Stratigraphy.

2.3 Depth of Cover

The depth of cover above the proposed D Seam longwall mine, located at the base of the stratigraphic sequence, ranges from 200 m above Longwall D406, to a maximum of 490 m in the northern part of the mine above the 1000 Series longwall panels (**Figure 7**).

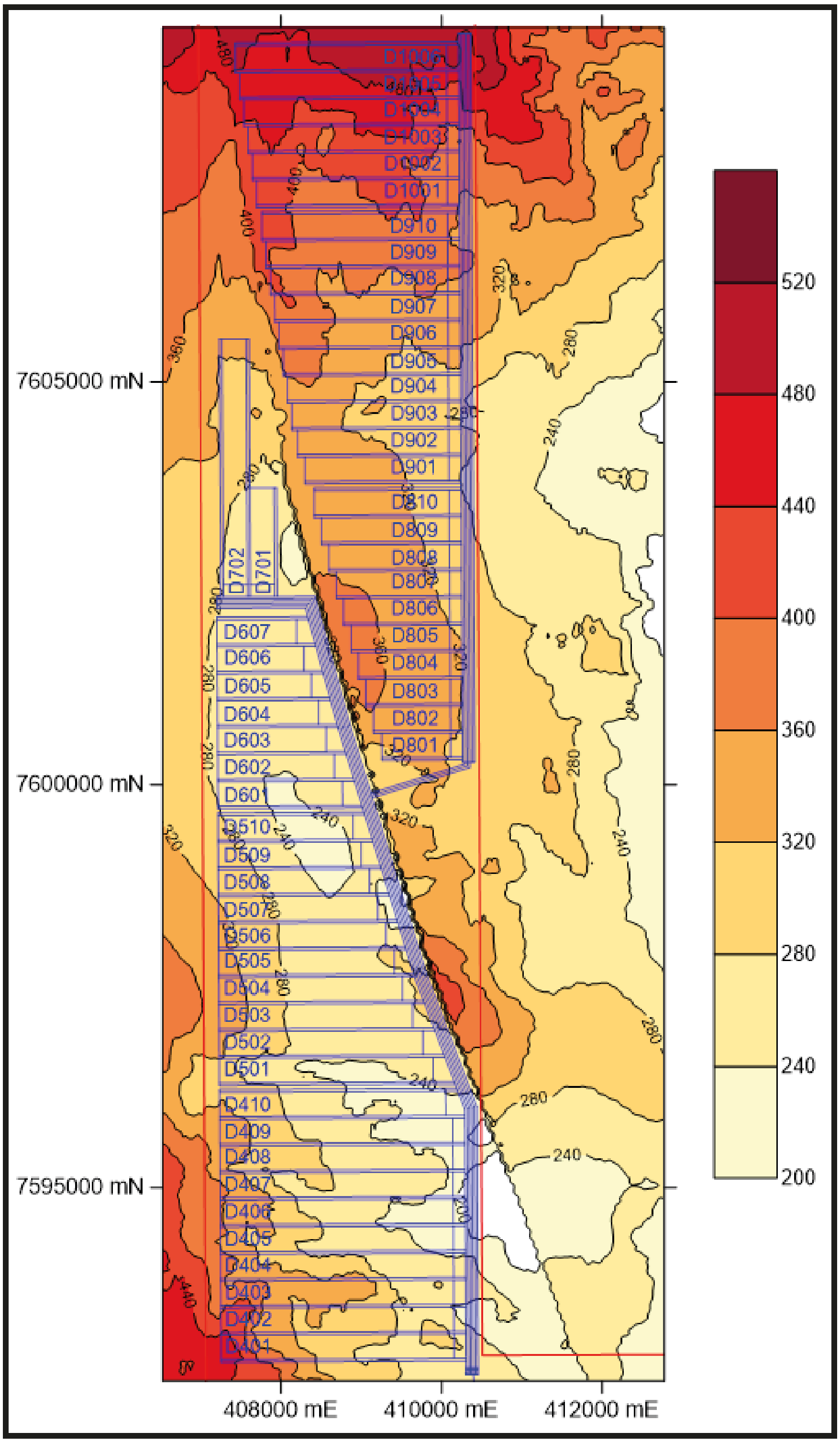

Figure 7. D Seam Depth of Cover (m).

The interburden between the A and D Seams is generally 50-70 m thick in the proposed mining area indicating that the A Seam longwall panels are located at depths of 140 m up to 420 m.

The C Seam longwall extraction ranges in depth from <100 m in the eastern part of the mine, to up to 450 m at the western end of Longwall C205 in the western part of the project site (**Figure 8**).

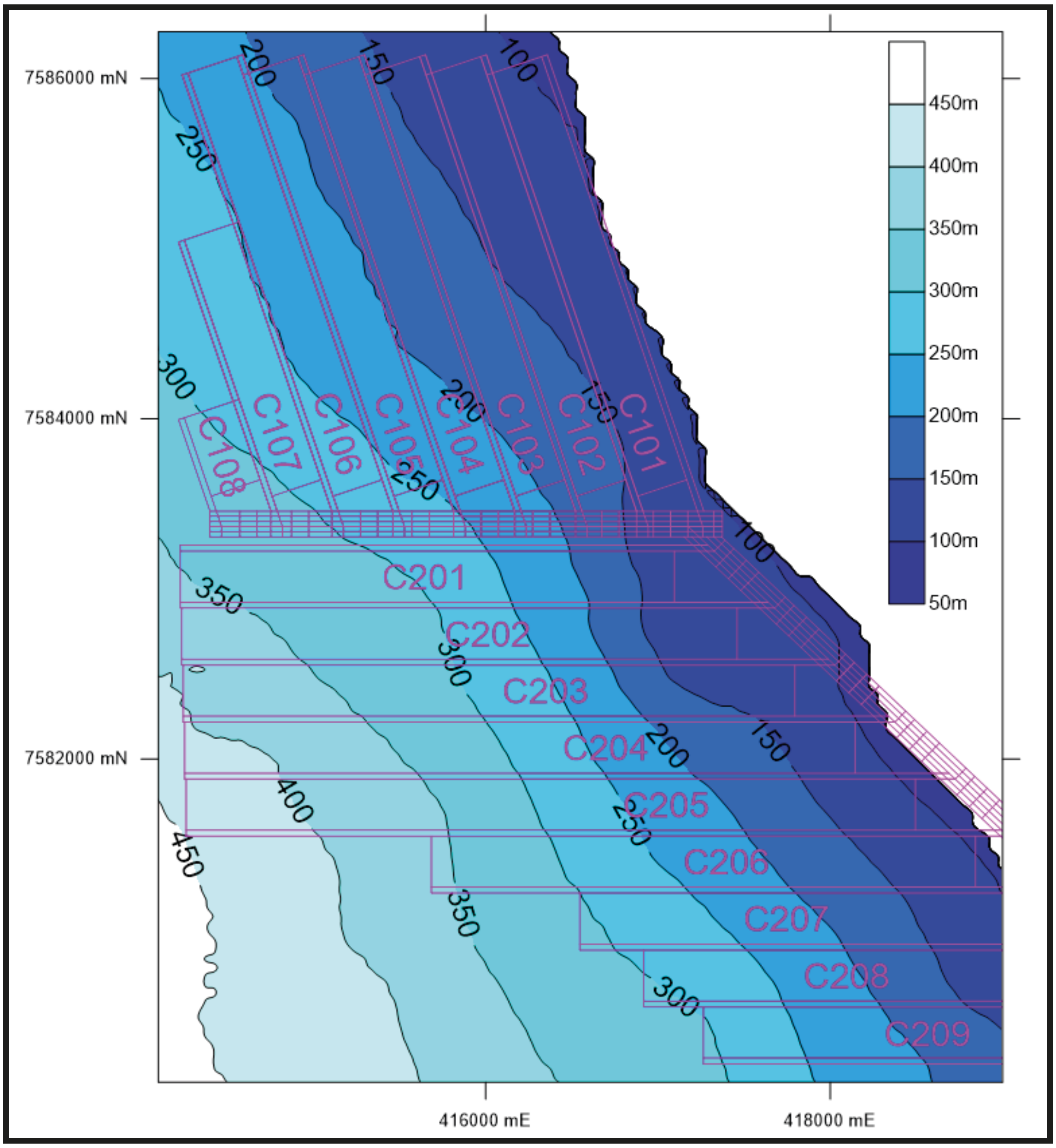

Figure 8. C Seam Depth of Cover (m).

2.4 Seam Thickness

The planned extraction height in the A and C Seams is 4.5 m. For the D Seam, due to the decrease in thickness from north to south, a progressive reduction in extraction height from 4.5 m to 3 m is planned. These extraction heights have been used in the subsidence models presented in section 4 of this report.

2.5 Floor Levels

The influence of the NW trending fault through the Northern Underground is clearly shown in **Figure 9**. This geological feature is downthrown by approximately 100 m towards the east.

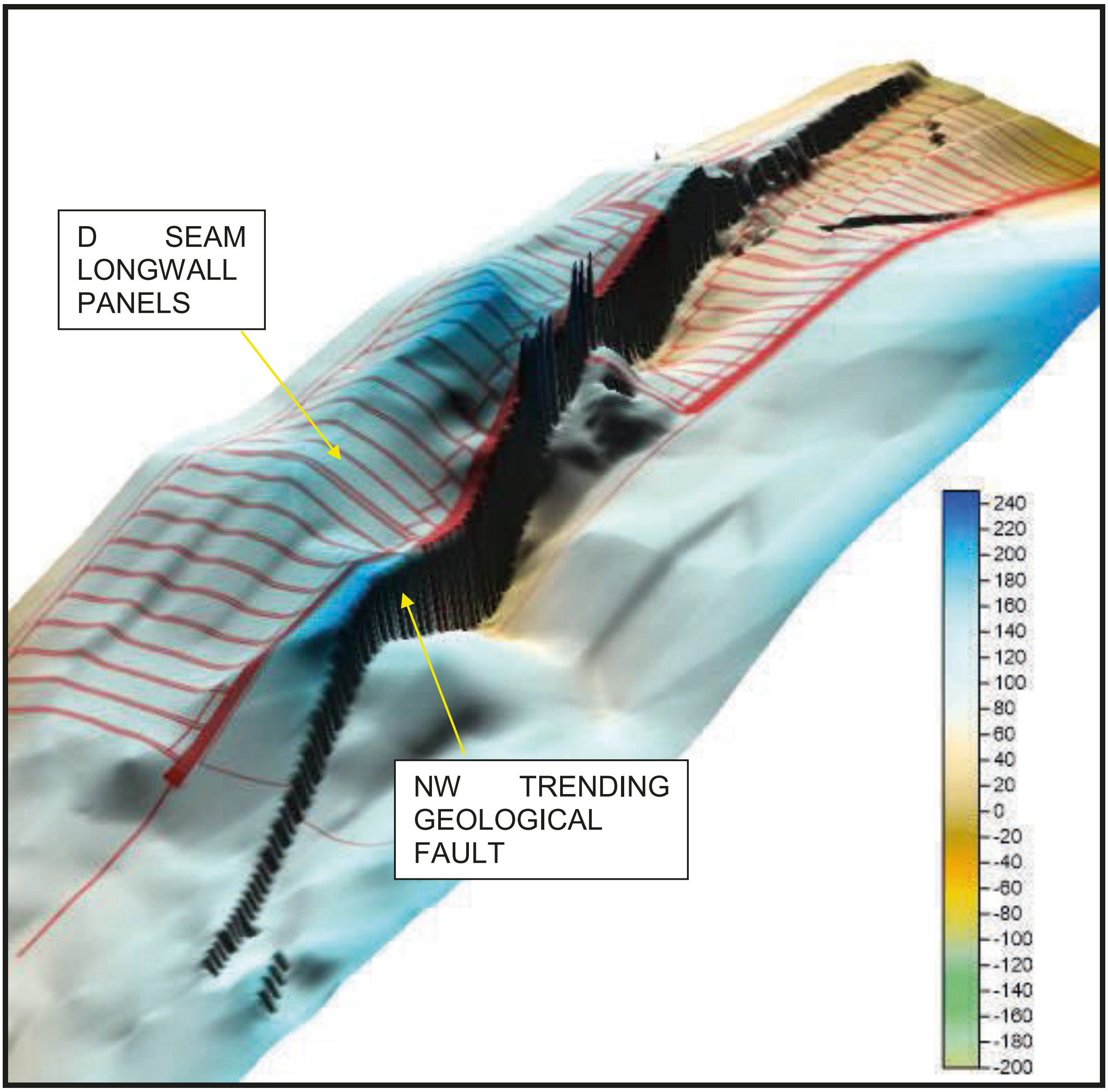

Figure 9. 3D Surface of the D Seam Structure Floor Levels (mASL).

3 SUBSIDENCE PREDICTION METHODOLOGY

3.1 Introduction to Surface Deformation Prediction System (SDPS)

GGPL has used the SDPS software to visualise the subsidence deformations in the project longwall mining areas. The SDPS program uses an influence function method that assumes the shape of a subsided surface can be modelled with a Gaussian (bell shaped) curve. This technique is a proven and reliable prediction methodology widely used throughout QLD and NSW, for EIS assessments and predictions of subsidence effects due to longwall mining beneath structures such as dams, highways and transmission towers[2].

The method requires calibration to existing survey data and mine geometry. The following inputs are required:

- Panel Layouts (corrected by the adjustment factor)
- Seam Thickness
- Depth of Cover
- Angle of Influence
- Subsidence Factor (maximum subsidence (S_{max})/extracted thickness ratio)
- Strain Coefficient

It should be noted that the SDPS methodology can only predict overall or systematic deformations. All subsidence surveys reveal small scale variations from the smooth profile predicted by this method. These deformations can be related to localised movements of blocky rock that is a feature of all coal mine overburdens.

Published dual seam longwall experience has also been referenced from the Australian and overseas coal mining industry.

Based on subsidence data from the neighbouring Bowen Basin presented in the South Galilee EIS (2012)[3], the following parameters were used for modelling in the proposed longwall mining areas:

- Panel Adjustment Factor of 0.2.
- Influence Angle of 77^o to maximise the tilts.
- Maximum Subsidence Factor of 60% for extraction in virgin ground and 75% for A Seam extraction above D Seam goaf areas.
- Strain Coefficient of 0.2.

These parameters are consistent with those used by GGPL at Bowen Basin mines for non-published subsidence studies. Similarities in the geology of the Bowen and Galilee Basins also justifies the application of these parameters to the project longwall mining areas. The coal bearing sequence in the project area was deposited at the same time geologically (late Permian) as the Bowen Basin coal measures.

[2] Byrnes R. 2003. Case studies in the application of influence functions to visualising surface subsidence. COAL2003 - 4th Underground Coal Operators Conference. AusIMM Illawarra Branch.
[3] South Galilee EIS (2012). Life of Mine Subsidence Deformations.

The overlying Rewan Formation in the project area, also occurs in the overburden of underground longwall mines such as Kenmare and Cook in the Blackwater area of the Bowen Basin and Newlands in the northern part of the basin.

Discussion of how these parameters were developed is included in the following sections. It should be highlighted that chain pillar deformations have not been analysed, resulting in a more conservative approach whereby the resulting strains and tilts are higher. This is due to the calculation of the subsidence above the chain pillars as simply the arithmetic sum of the subsidence developed above adjacent "isolated" panels.

3.2 Subsidence Behaviour

The subsidence above longwall panels is comprised of two main components namely sag subsidence and strata compression. Depending on the depth of cover and width of extraction these components combine in various proportions (**Figure 10**).

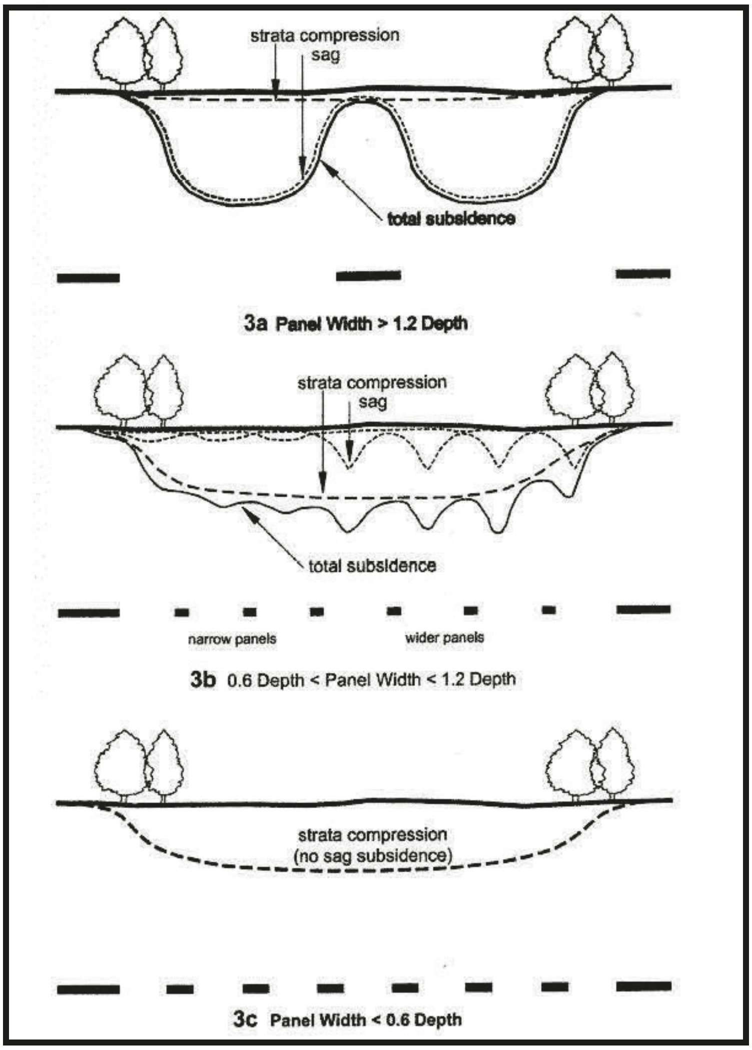

Figure 10. Effect of Panel Width (AusIMM, 2009[4]).

[4] AusIMM (2009). Australasian Coal Mining Practice – Monograph Series 12. Pp1085.

At the planned depths and panel widths in the proposed mining areas, the sag subsidence is expected to be a large component of the total subsidence in the majority of the proposed longwall mining areas (**Figure 10**). This is termed supercritical subsidence. In these areas, the maximum vertical subsidence does not increase as the panel width increases.

In the deeper longwall mining areas at the project site, where the panel width/depth ratio is <1.2, strata compression will contribute a higher component of the total subsidence (**Figure 10**).

Due to the extraction of the A Seam longwall panels above the D Seam longwall

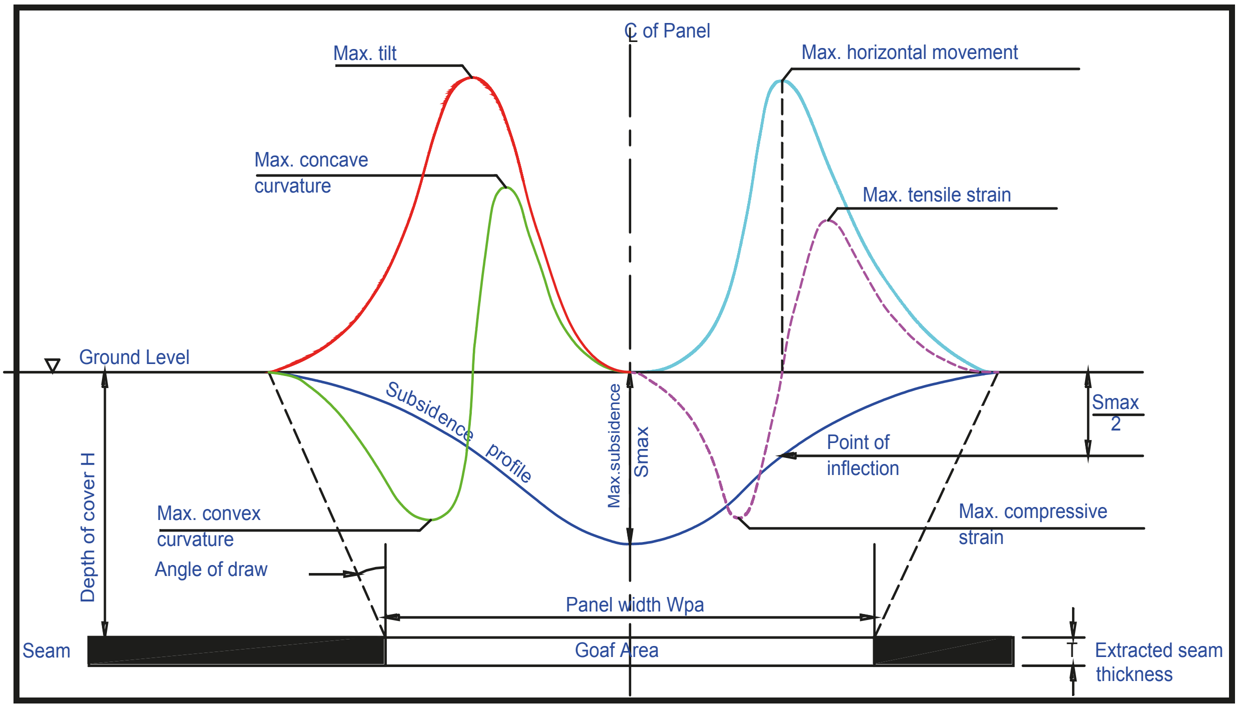

Figure 11. General Characterisation of a Subsidence Cross Line.

- The areal extent of subsidence is defined by the angle of draw. Conventionally the angle of draw is measured from the point of 20 mm of vertical subsidence (not zero), which equates to the limit of measurable subsidence (LOMS). Subsidence less than 20 mm will have a negligible effect, as it cannot be differentiated from natural ground surface variations due to soil moisture changes.
- Maximum tilt should correspond with zero strain.
- The subsidence at the point of maximum tilt and zero strain should be ½ the maximum vertical movement.

- The maximum tilts or strains do not necessarily correspond with the edge of the extraction.

These parameters characterise the surface deformations above the extracted longwall panels and provide context to the resulting impacts.

3.3 Determination of Subsidence Factors

3.3.1 Single Seam

A subsidence factor ratio of maximum subsidence (S_{max}) to extracted thickness (T) in virgin ground has been estimated from Bowen Basin data and empirical data from NSW (**Figure 12**). This ratio is the percentage of the extracted thickness underground, measured as subsidence on the surface. It should be highlighted that an empirical curve has not been developed for the Bowen Basin due to fact that the majority of the extraction has been carried out at panel width:depth of cover ratios >0.8 (**Figure 12**).

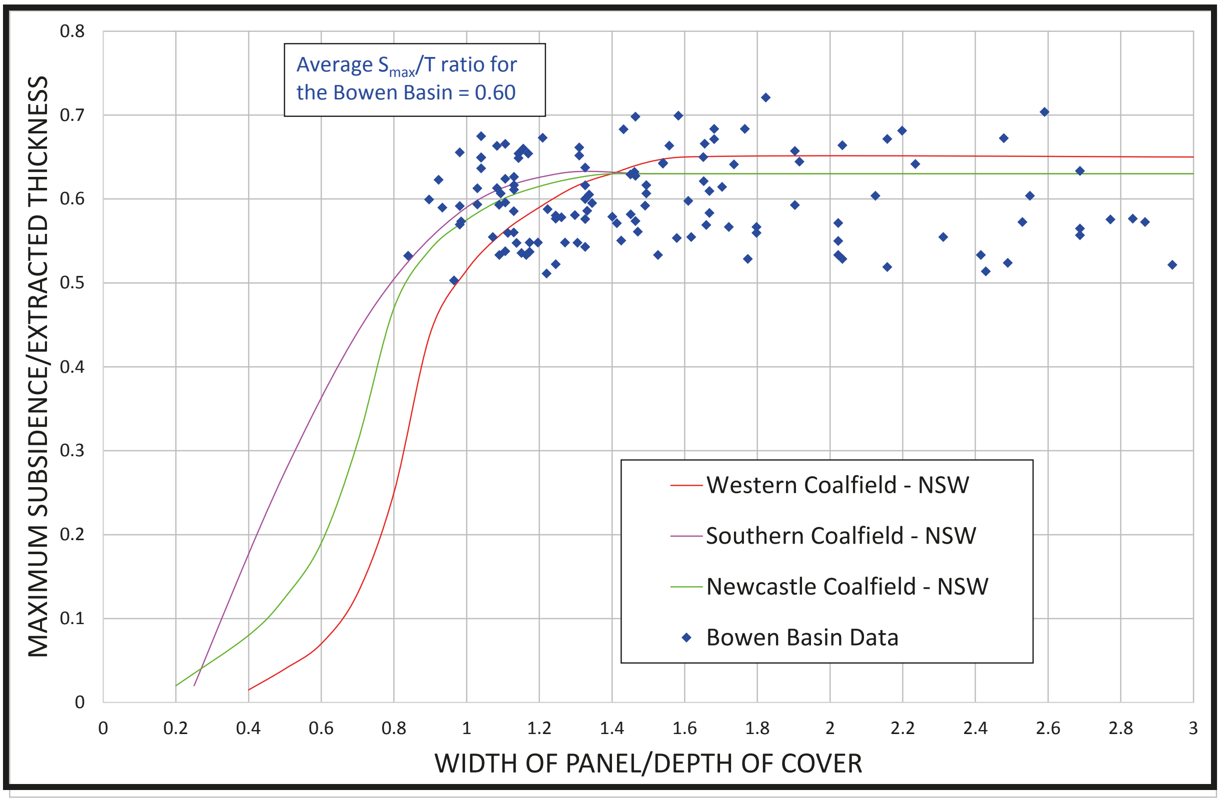

Figure 12. Empirical Curves for Sag Subsidence over Single Panels in Virgin Ground.

Available Bowen Basin data validates the application of a 60% subsidence factor to the project longwall area for extraction in virgin ground (**Figure 12**). In localised parts of the proposed mining area, the ratio of the panel width:depth ratio is less than 1. In these areas the subsidence factor has been correspondingly reduced in SDPS, based on the empirical subsidence curves presented in **Figure 12**.

3.3.2 Dual Seam

Li et al (2010), have recently reported experience in dual seam longwall extraction[5]. In their case study, subsidence data for over-mining at Cumnock and North Wambo mines was presented.

At these mines the upper seams are located 43 m and 180 m, respectively, above the lower seams which were extracted first. The A Seam in the project site is typically 50-70 m above the D Seam and hence is located between these two data sets.

The subsidence factor at Cumnock is 78% of the extraction height for the upper seam, compared to 67% at North Wambo (**Table 1**).

Mine	Seam	Seam Thickness (m)	Depth (m)	S_{max} (m)	Subsidence Factor (Lower Seam)	Subsidence Factor (Upper Seam)	Subsidence Factor (Both Seams)
Cumnock	Upper	2.2	90	1.72		78%	
	Lower	2.5	133	1.25	50%		
	Both	4.7		2.97			63%
Wambo	Upper	2.6	80	1.74		67%	
	Lower	3.3	260	1.57	48%		
	Both	5.9		3.31			56%

Table 1. Subsidence Parameters from Cumnock and Wambo (Li et al, 2010).

Based on this data, a conservative maximum 75% subsidence factor has been applied to the A Seam extraction located in the fractured zone of the D Seam extraction (**Figure 13**). In areas of lower ratio panel width to depth of cover, the subsidence factor was correspondingly reduced in line with empirical data.

MSEC (2007)[6] also proposed that the additional ground movement in a dual seam mining environment is dependent upon the thickness of the interburden between the seams, as well as the thickness of the seams to be extracted.

In the case of the combined A and D Seam extraction, the total subsidence at any point is a simple addition of individual values for each seam. The same is not true of the strain and tilts. SDPS has the facility to allow models to be run with both seam layouts simultaneously, to provide outputs of these parameters. This methodology has been utilised in areas where both the A and D Seams are extracted.

[5] Li, G., Steuart, Paquet, R., and Ramage, R (2010). A case study on mine subsidence due to multi-seam longwall extraction. 2nd Australasian Ground Control in Mining Conference. Pp. 191-200.

[6] Mine Subsidence Engineering Consultants (2007). General discussion on systematic and non systematic mine subsidence ground movements. Revision A, August 2007.

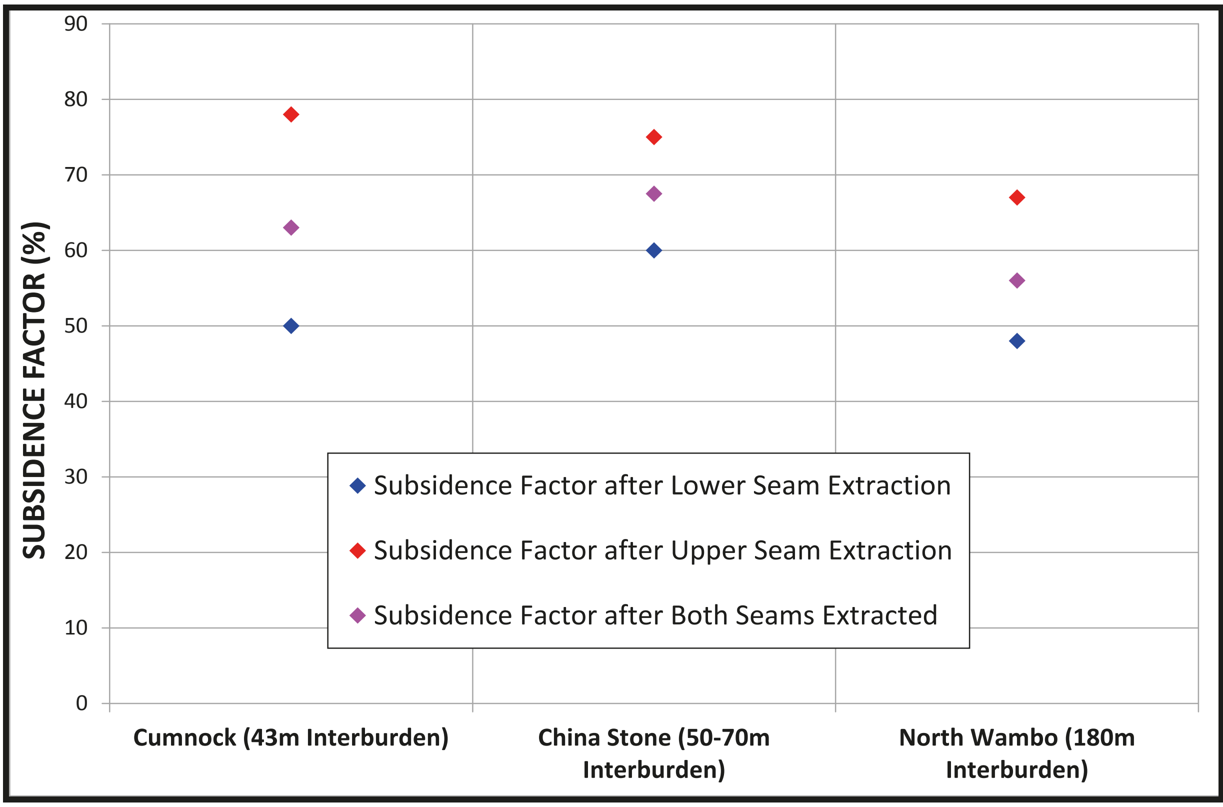

Figure 13. Subsidence Factors for Dual Seam Extraction.

3.4 Determination of the Influence Angle

Using subsidence data from the Bowen Basin presented in the South Galilee EIS (2012), a high influence angle of 77^o was used in the modelling. For the A Seam, it is likely that the rock mass may be broken due to extraction of the underlying D Seam and not able to span, resulting in high influence angle values. Whilst the influence angle for the D Seam may be less than the 77^o assumption, this value is considered conservative for the purpose of the EIS. In the absence of dual seam subsidence data, the 77^o is considered appropriate to apply to extraction in the A Seam, as well as the C and D Seams.

3.5 Determination of the Panel Adjustment Factor

SDPS considers each extraction panel not by the mining edge but by the projection of the points of inflexion. The compensation width is the distance from the rib edge to the inflexion point or point of half-maximum subsidence. For wide extraction panels, the position of the inflexion points is a linear proportion of the depth of cover.

The panel adjustment factor is the compensation width divided by the depth of cover, where the compensation width is the distance measured from the rib edge to the inflection point or point of half maximum subsidence (**Figure 11**).

An average value of 0.2 was determined for the panel adjustment factor from the available published Bowen Basin data (South Galilee EIS, 2012). For the SDPS analysis of the C Seam mine, the original and compensated longwall panel boundaries are shown in **Figure 14**. Compensated boundaries were also determined for both the A and D Seam layouts using the same panel adjustment factor.

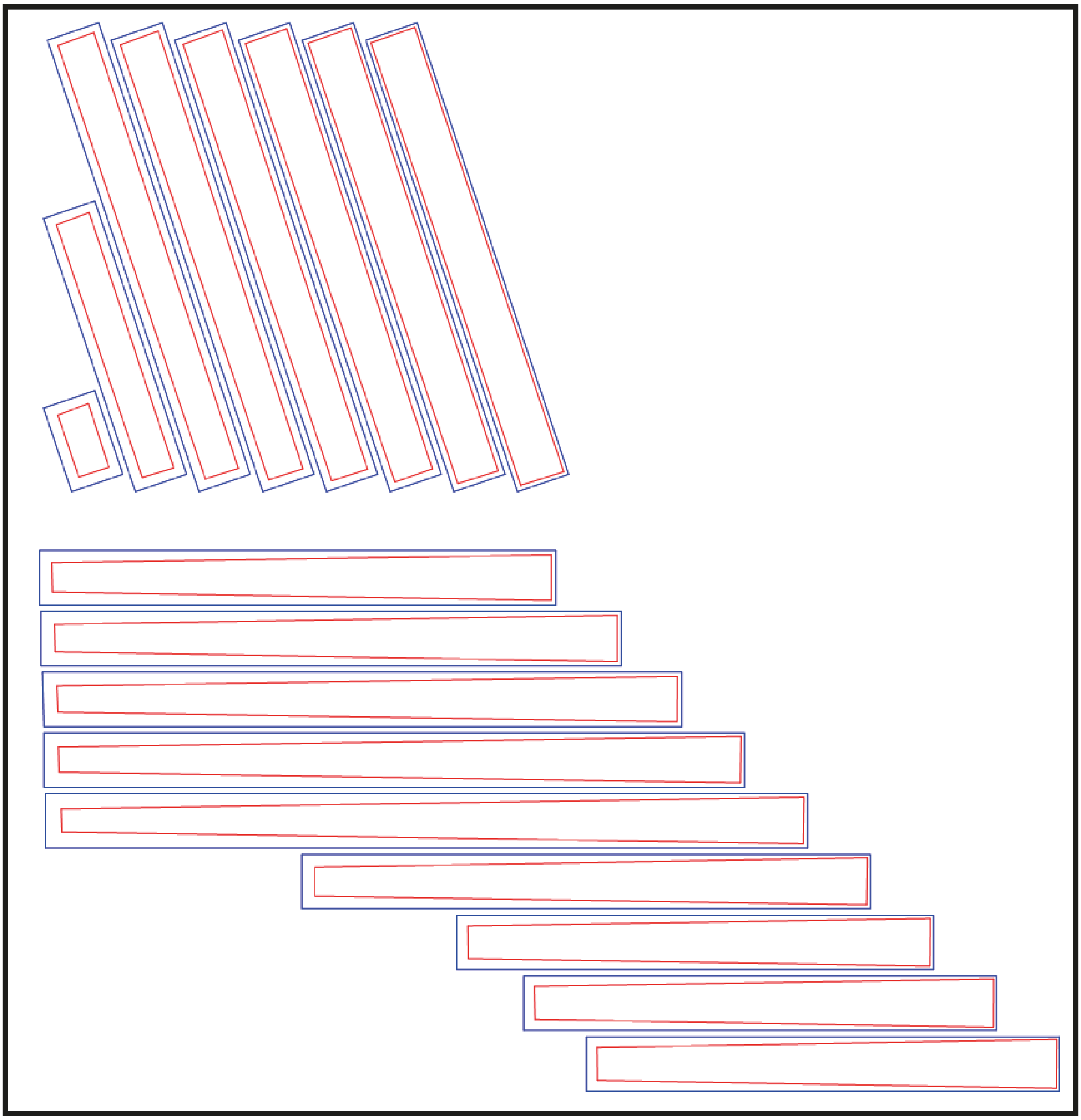

Figure 14. C Seam Longwall Mine - Original Longwall Panels (blue) and Compensated Panels (red).

3.6 Determination of the Strain Coefficient

Strain data is particularly affected by blocky rock movements and often show a large degree of dis-ordered movement. A strain coefficient of 0.2 has been used for the subsidence modelling work in the proposed longwall area, based on the Bowen Basin data presented in the South Galilee EIS (2012).

3.7 Analysis of Massive Spanning Units

For completeness, the potential for spanning massive units in both the Triassic and Permian strata above the A, C and D Seams has been assessed.

3.7.1 Permian Overburden

Conservatively assuming a 20° caving angle, a typical rock strength of 60 MPa and a modulus of 12 GPa, a voussoir beam analysis indicates that a 49 m thick massive unit in the Permian overburden is required to span a 300 m wide longwall panel.

The variability in the gamma response of the A, C and D Seam Permian overburden in selected exploration drill holes across the longwall mining areas, indicates that any massive units are less than 30 m thick (**Figure 15, Figure 16 and Figure 17**). The potential for spanning units in the Permian overburden is therefore unlikely and it is anticipated that caving behind the retreating longwalls will occur readily.

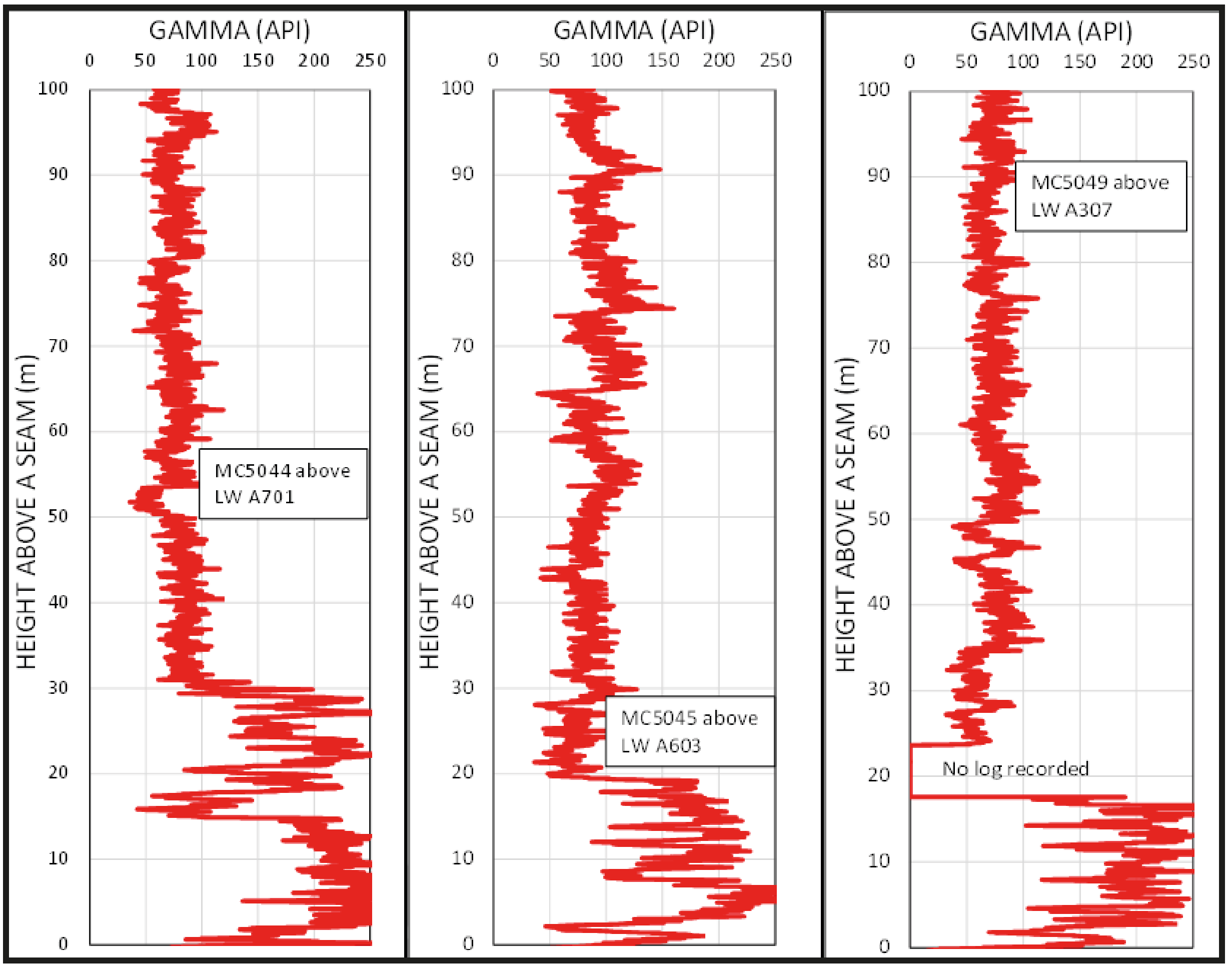

Figure 15. Gamma Response of the A Seam Overburden.

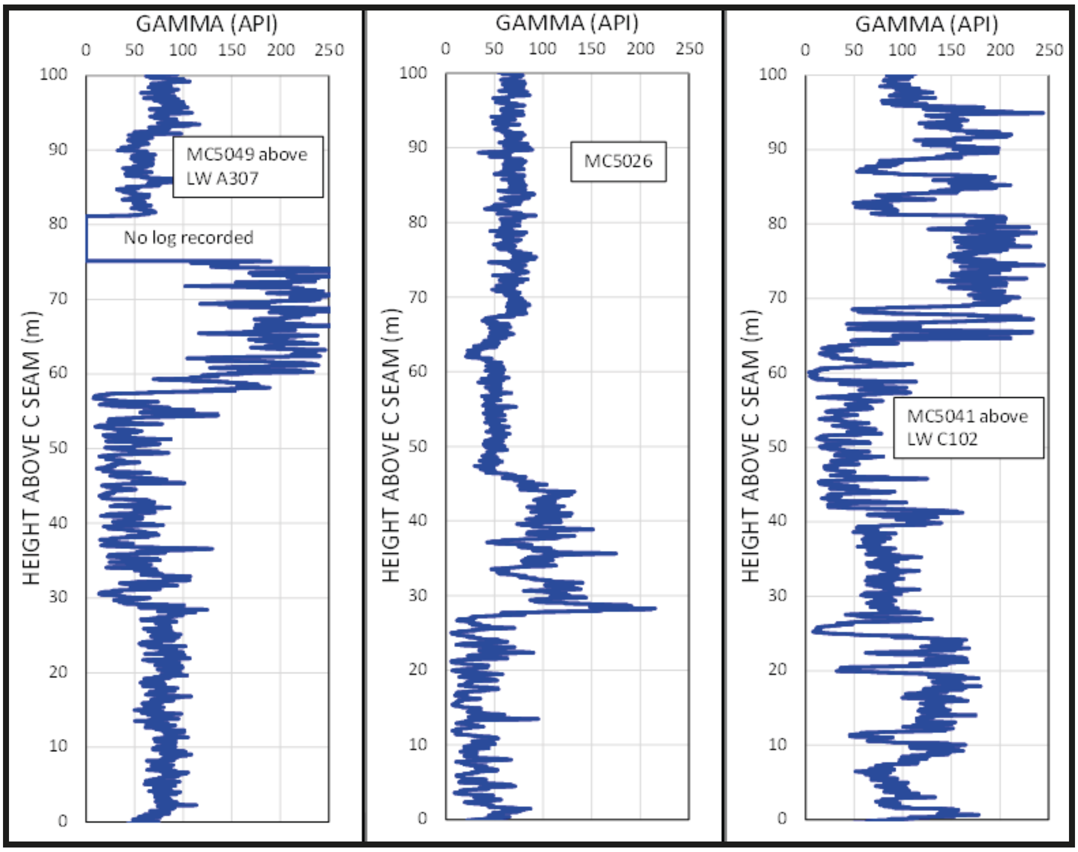

Figure 16. Gamma Response of the C Seam Overburden.

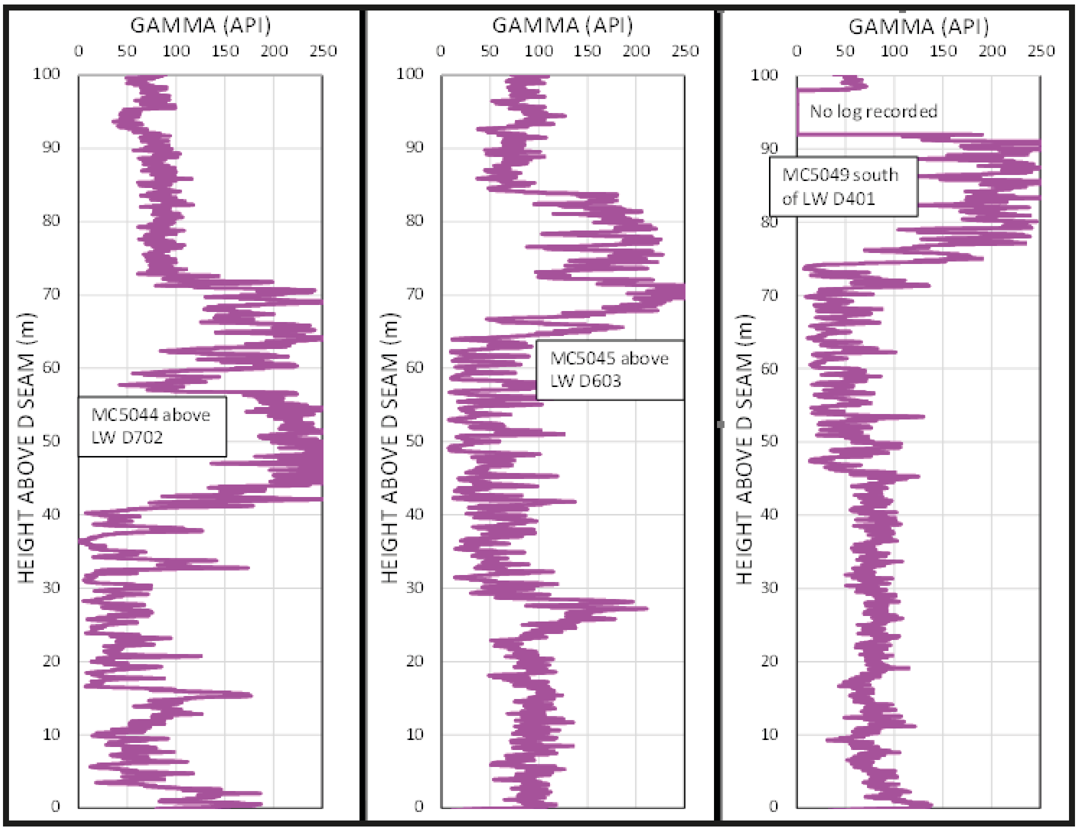

Figure 17. Gamma Response of the D Seam Overburden.

3.7.2 Triassic Clematis Sandstone

The potential for spanning of the Triassic Clematis Sandstone also needs to be assessed. The gamma logs, in conjunction with core photographs and lithological logs suggest an upper bound thickness for massive layers in this sandstone unit of 40 m.

Voussoir beam analysis of a 40 m thick Clematis Sandstone unit, located 120 m above the A Seam, indicates that as the depth increases the strength of the sandstone required to span increases to more than 100 MPa, at depths greater than 270 m (**Figure 18**). This analysis indicates that for a typical rock strength of 20 MPa this unit is not likely to be able to span a 300 m wide longwall panel.

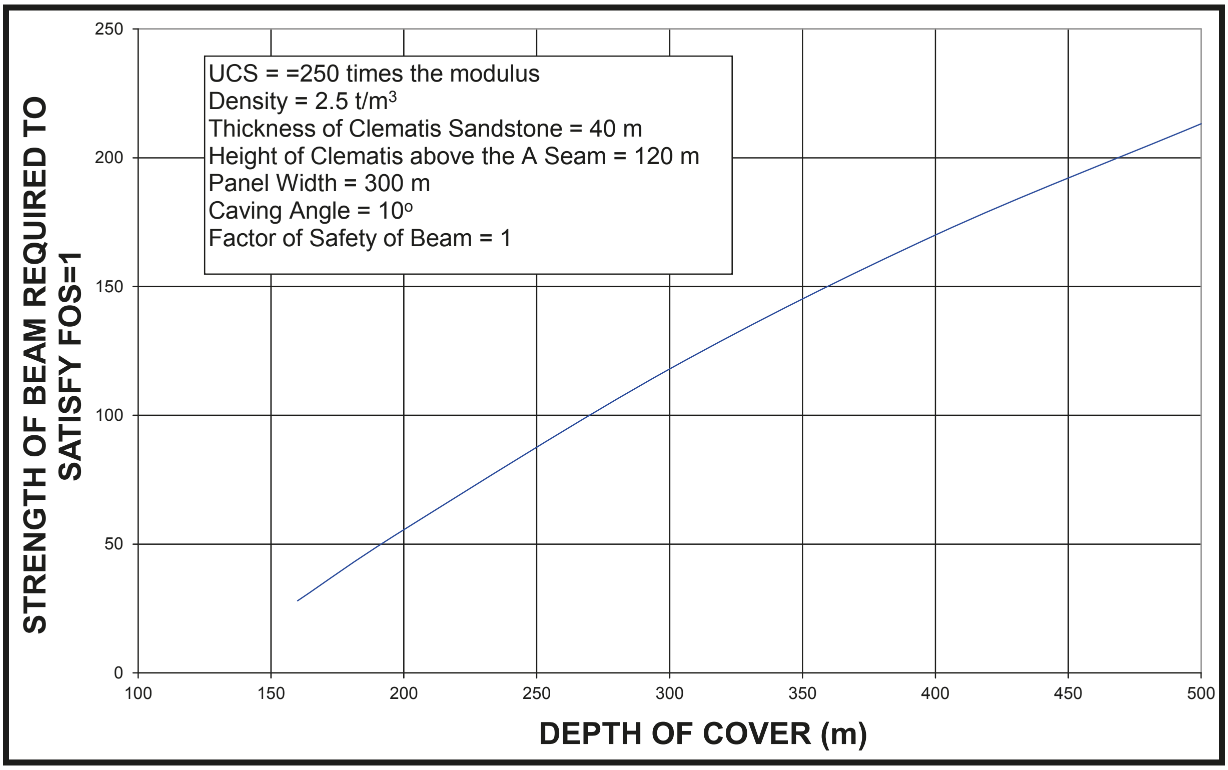

Figure 18. Sensitivity Analysis of the Strength of the Clematis Sandstone Required to Span a 300 m Wide Longwall Panel.

4 SUBSIDENCE PREDICTIONS

The results of running the SDPS models for the A, C and D Seam longwall mines are presented in the following sections. Subsidence modelling was carried out individually for both the C and D Seam and also for the combined A and D Seams.

4.1 Northern Underground

4.1.1 A and D Seam Subsidence

Predicted total subsidence from mining of the A and D Seam longwall panels is shown in **Figure 19**. Vertical subsidence reaches a maximum of 6 m in the shallower mining areas in the western part of the Northern Underground and is often >5 m. In the deeper parts of the Northern Underground, the maximum vertical subsidence reduces to 4 m. In the southern part of the area, where only the A Seam is extracted, the maximum subsidence is <2.5 m.

As well as vertical movement, minor horizontal ground movements also occur at the surface due to underground mining. These movements are more relevant if key surface infrastructure is located above the longwall extraction area. The potential horizontal displacements due to longwall mining are considered to be minor and are not considered a significant additional effect in the project area.

With the improvement in surveying techniques over the years, “far-field” effects have been measured outside the conventional 26.5^{o} angle of draw. If an elastic analysis of a rock mass is carried out, both vertical and horizontal movements of less than 20 mm are indicated outside the angle of draw consistent with the survey measurements. The horizontal movements are greater than the vertical but because of the very low magnitude of the movements, the strains are negligible. These minor horizontal movements are typically towards the extraction area (AusIMM, 2009).

These “far-field” effects do not occur below the surface and only occur where there is a free face, such as the steep sided valleys, which are characteristic of the Southern Coalfield of NSW. In this coalfield, vertical cliff faces may be greater than 100 m high. This behaviour is confirmed by the strong influence on the magnitude and direction of horizontal movements of the surface topography detailed in the 2009 AusIMM subsidence paper. In the less severe topography above the project longwall mining areas, no significant far field effects are expected.

4.1.2 A and D Seam Surface Strain

Bending and horizontal movements in the strata cause surface strain. Measured strain is determined from monitored survey data by calculating the horizontal change in length of a section of a subsidence profile and dividing this by the initial horizontal length of that section.

The maximum predicted tensile strains after the extraction of both the A and D Seams range in magnitude up to 36 mm/m (**Figure 19**). In all cases, maximum tensile strains are expected to occur over the chain pillars. Maximum compressive strains range up to 31 mm/m.

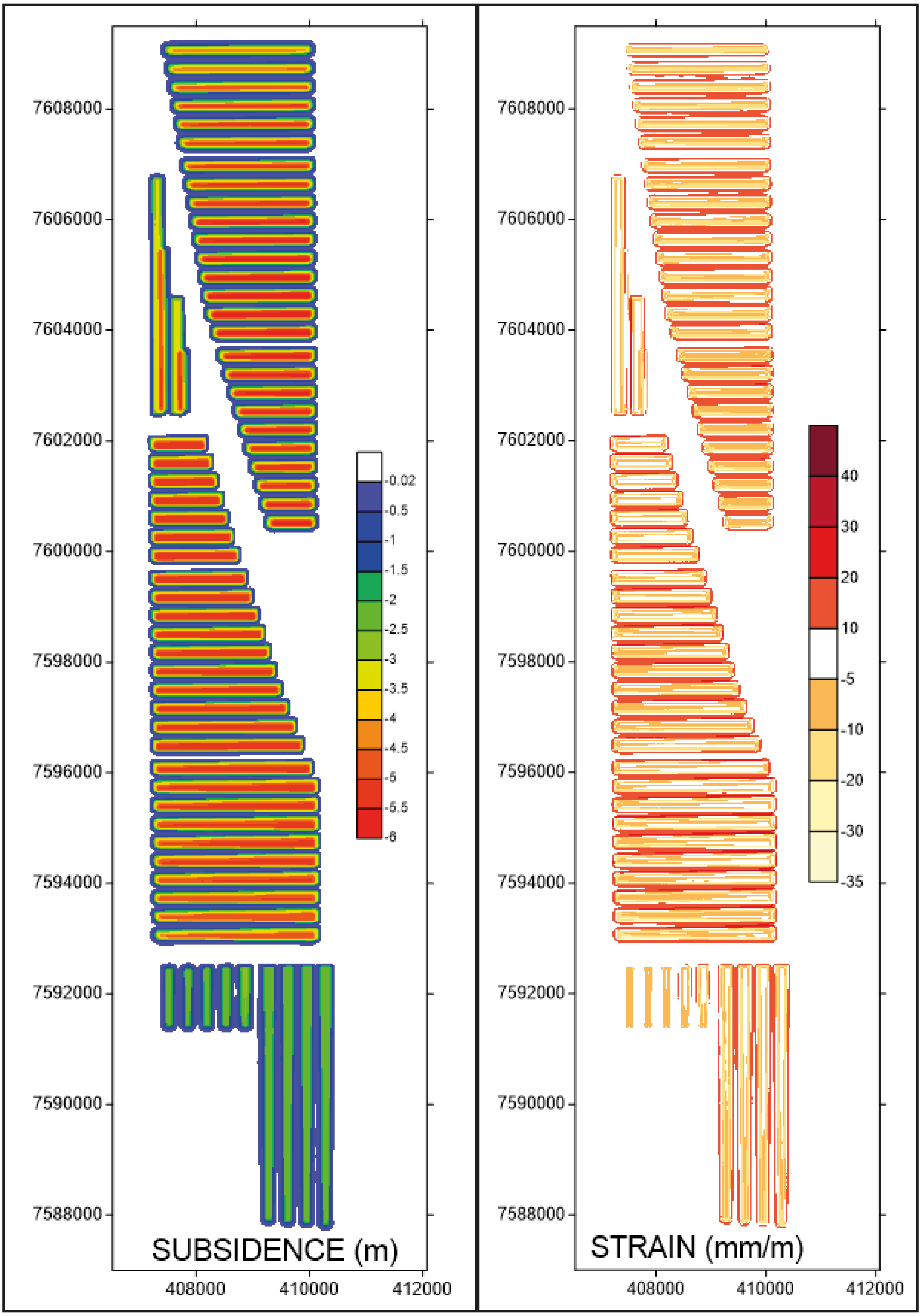

Figure 19. Subsidence and Strain due to A and D Seam Longwall Extraction.

4.1.3 A and D Seam Tilt

Tilt is the slope of subsided land over a given distance and is calculated by determining the change in subsidence between two points and dividing this by the distance between those points. The physical result is that the post mining surface slopes become steeper in localized areas along the edges of the subsidence troughs. Maximum tilts developed on the surface after the extraction of both the A and D Seam range up to 11% or 110 mm/m (**Figure 20**).

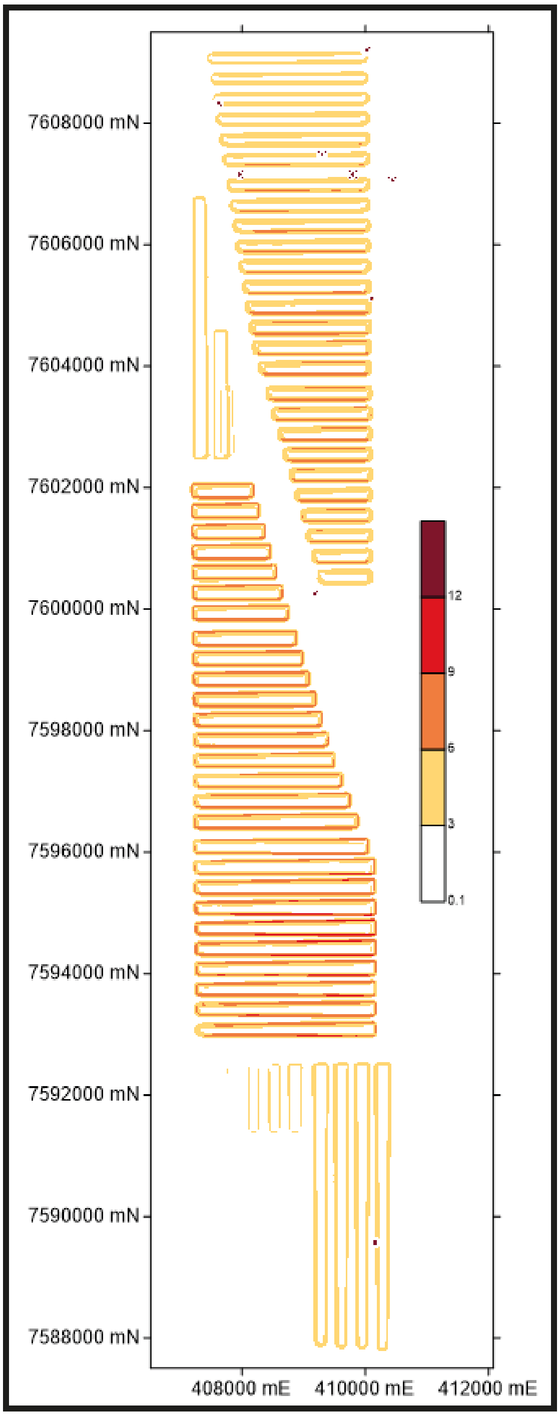

Figure 20. Tilt due to A and D Seam Longwall Extraction (%).

4.1.4 D Seam Subsidence, Strain and Tilt

The subsidence effects due to D Seam extraction only, are also presented in **Figure 21**. A maximum vertical subsidence of 2.6 m is predicted above Longwalls D902 and D903 (**Figure 21**). Maximum compressive and tensile strains are 11 mm/m above longwalls D901 to D903. Similarly, maximum tilts approach 3.9 % or 39 mm/m above the same longwalls.

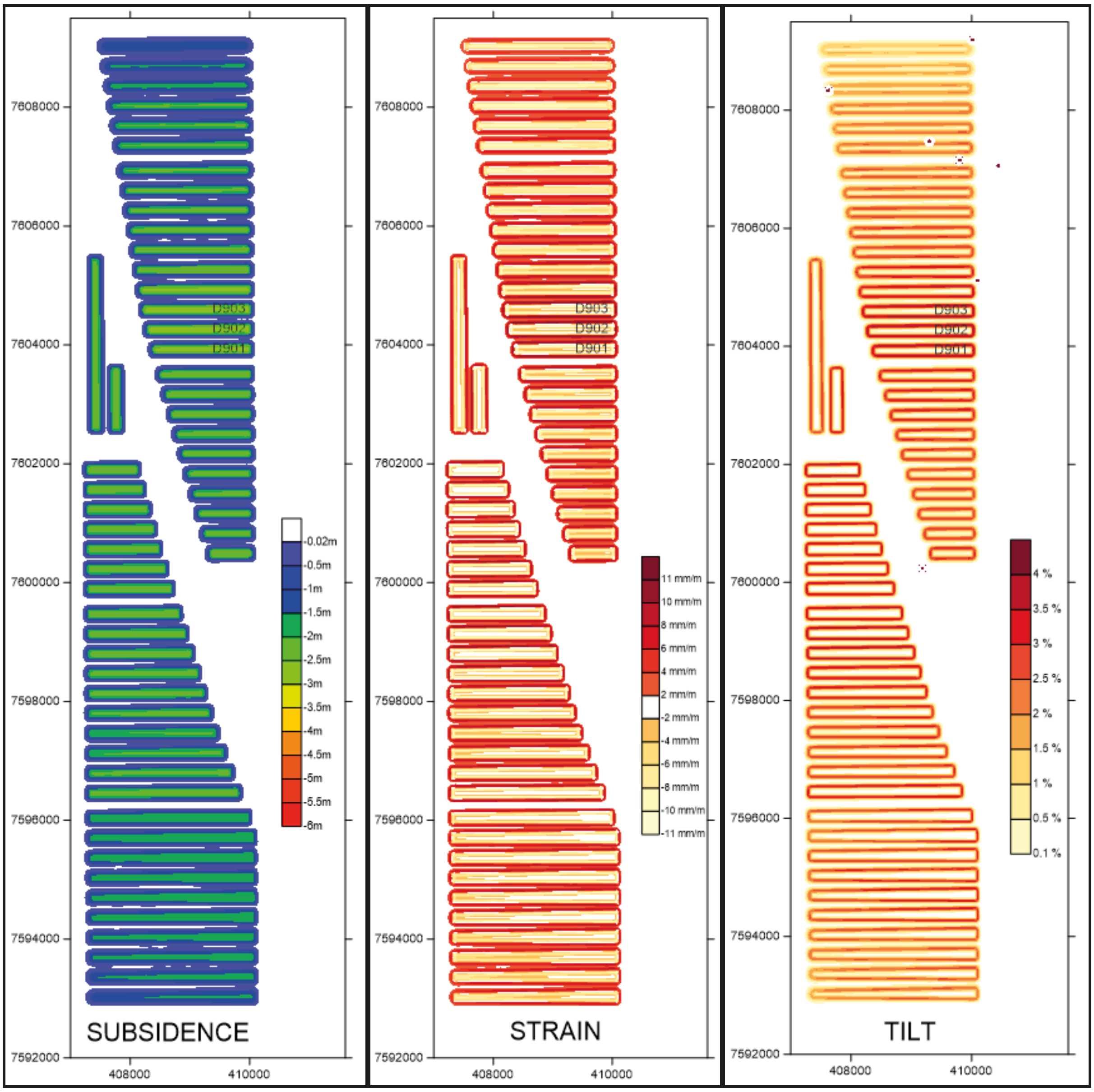

Figure 21. Subsidence, Strain and Tilt due to D Seam Longwall Extraction.

4.1.5 Cross Sections

Subsidence profiles can also be graphically represented on cross lines such as those shown in **Figure 22**, across the proposed longwall mining areas. It should be highlighted that these sections have a **very large vertical exaggeration** such that the tilts shown in the figures are very much larger than will be induced by the subsidence. The subsidence, strain and tilt profiles along cross line 1 in the Northern Underground area are shown on **Figure 23**.

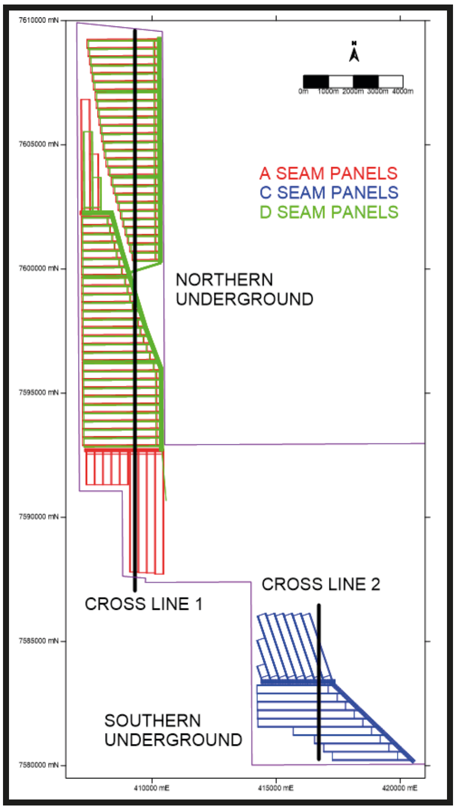

Figure 22. Location of Cross Lines.

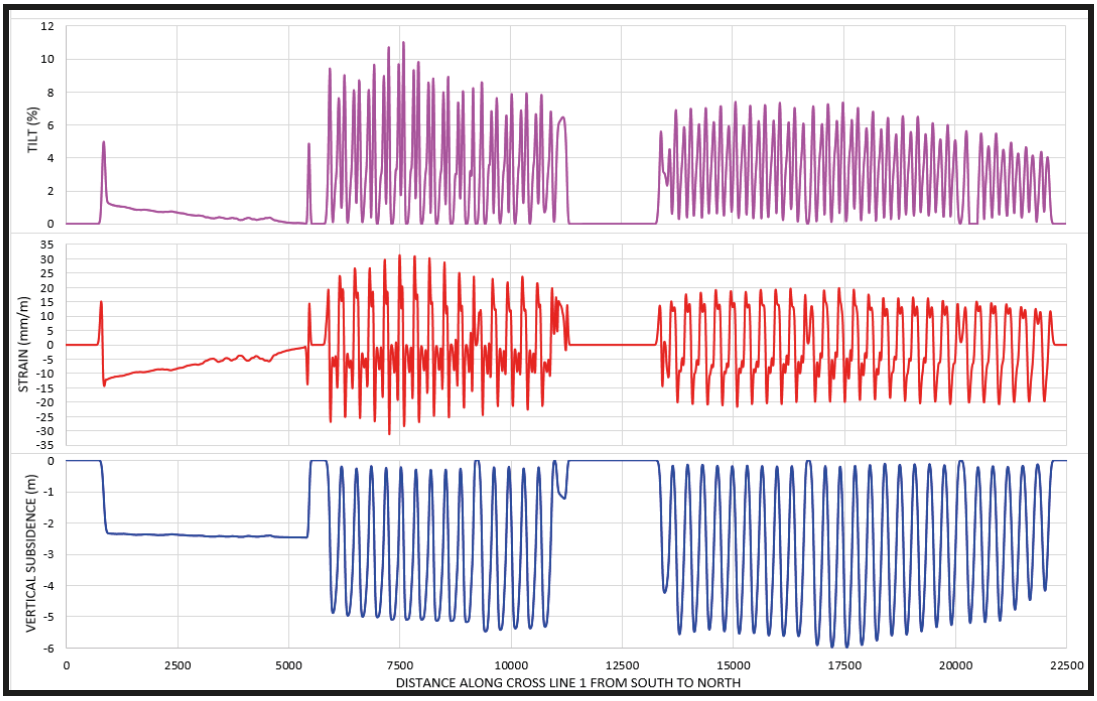

Figure 23. Subsidence, Strain and Tilt along Cross Line 1.

4.2 Southern Underground

4.2.1 C Seam Subsidence

Predicted subsidence from the C Seam longwall mine is shown in **Figure 24**. Vertical subsidence reaches a maximum of 2.7 m in the shallower mining areas. In the deepest part of the mining area maximum subsidence reduces to <2.2 m.

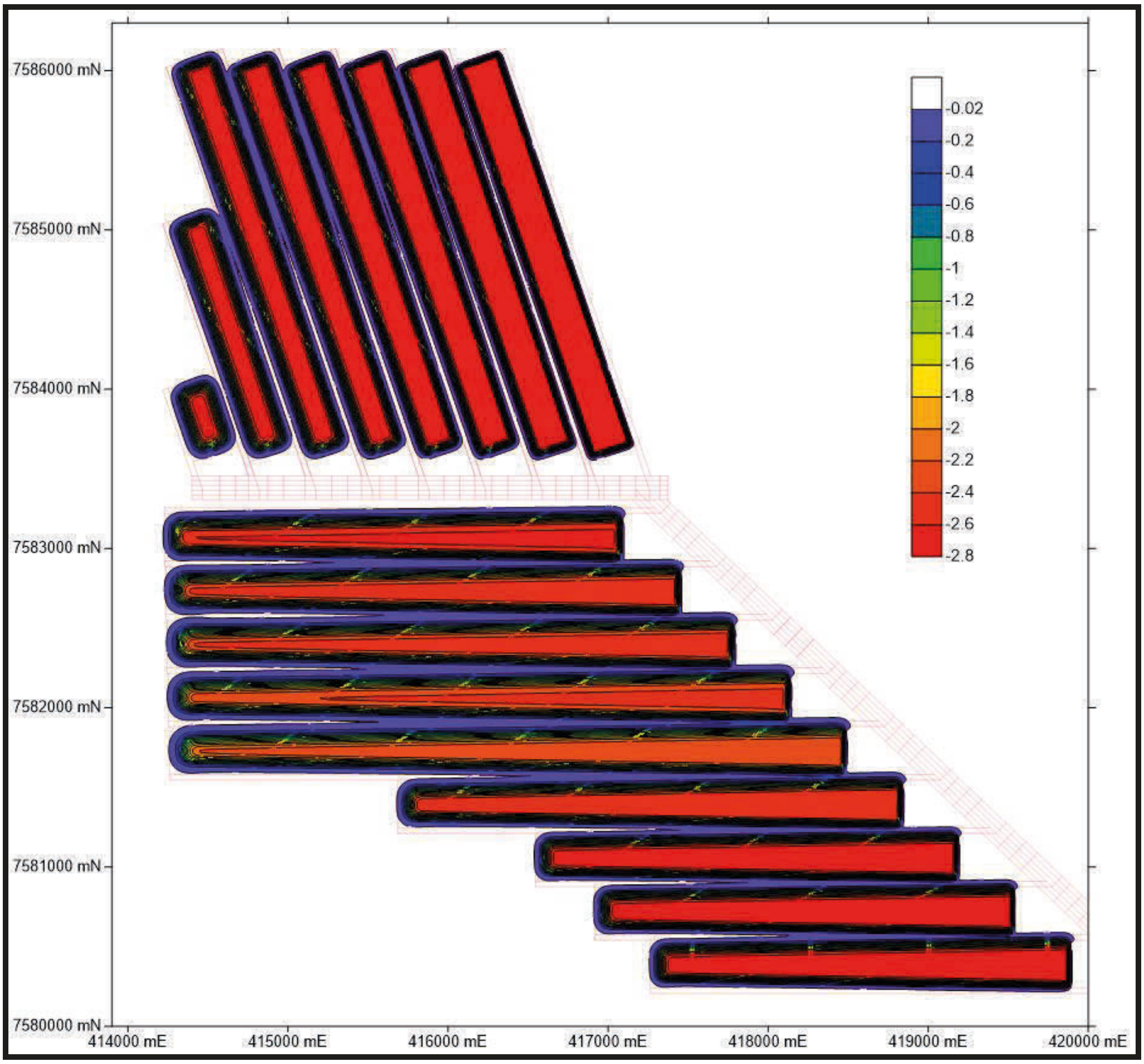

Figure 24. Subsidence due to C Seam Longwall Extraction (m).

4.2.2 C Seam Surface Strain

The maximum tensile strains caused by the C Seam longwall extraction range in magnitude up to 59 mm/m (**Figure 25**). Maximum compressive strains range up to 55 mm/m.

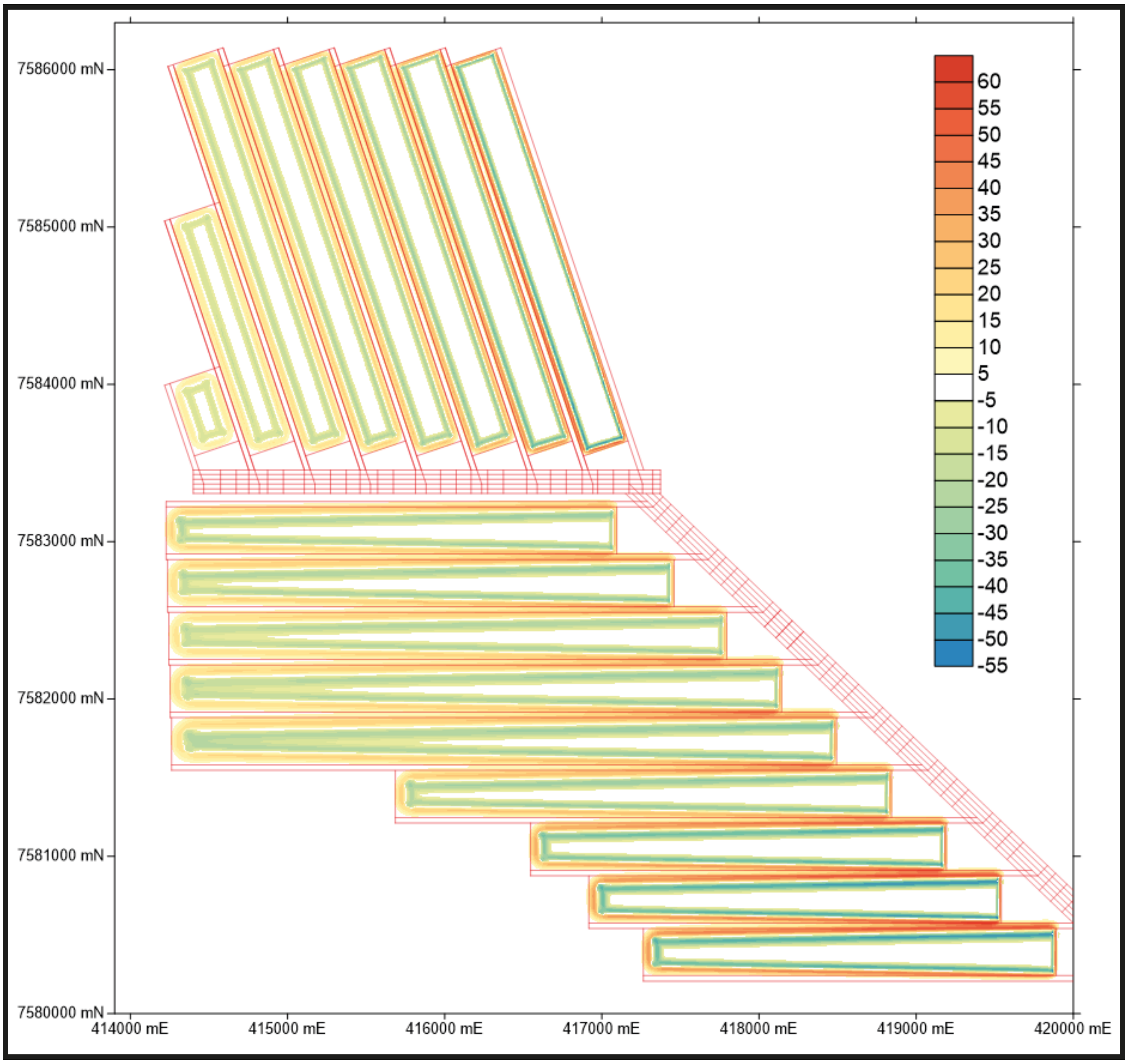

Figure 25. Strain due to C Seam Longwall Extraction (mm/m).

4.2.3 C Seam Tilt

The maximum tilts developed due to extraction of the C Seam longwalls are higher than in the shallowest part of the Northern Underground. They range up to 16.5% or 165 mm/m in the shallower, southeastern corner of the Southern Underground (**Figure 26**).

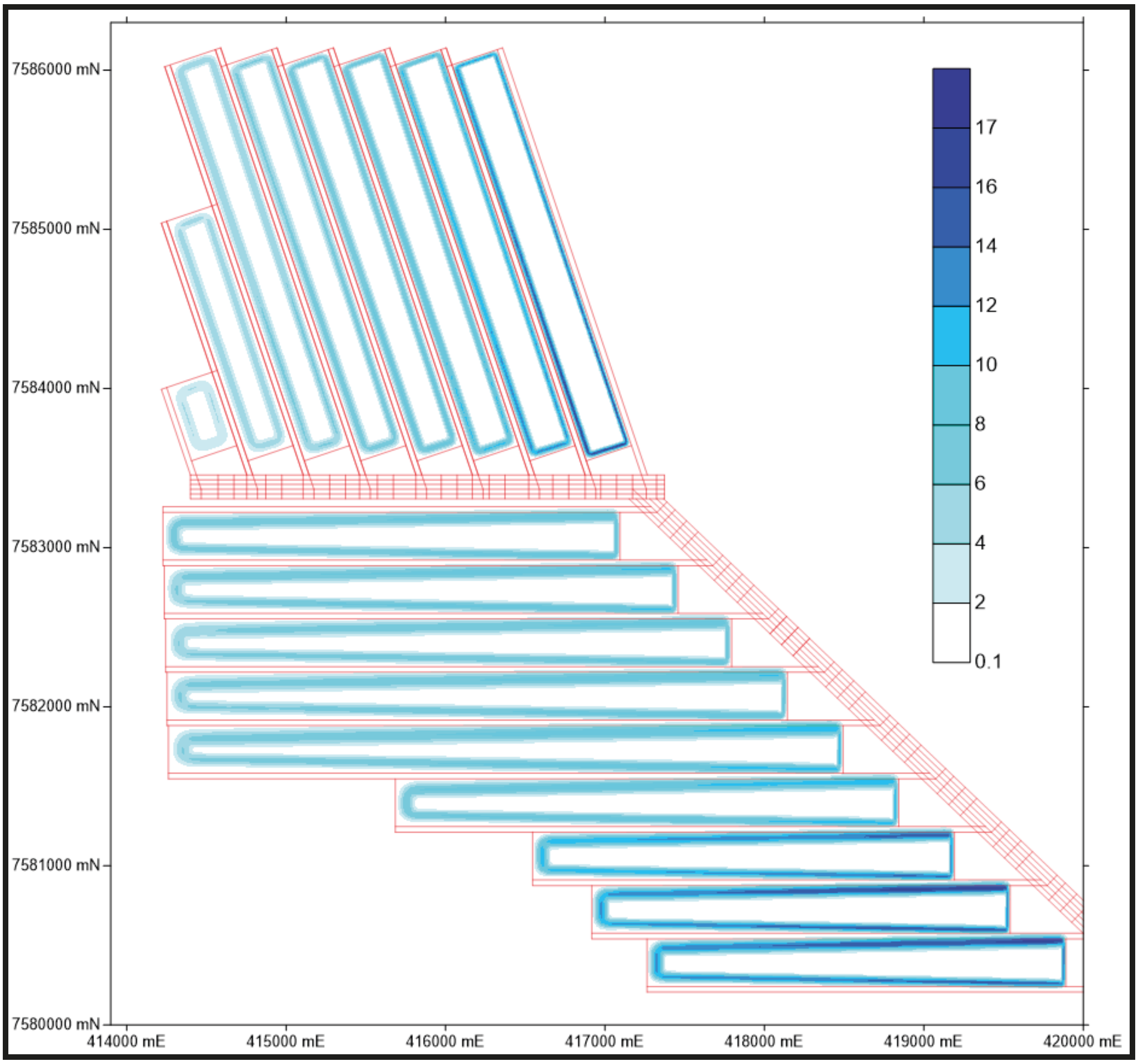

Figure 26. Tilt due to C Seam Longwall Extraction (%).

4.2.4 Cross Sections

The subsidence, strain and tilt profiles along cross line 2 in the Southern Underground area are shown on **Figure 27**.

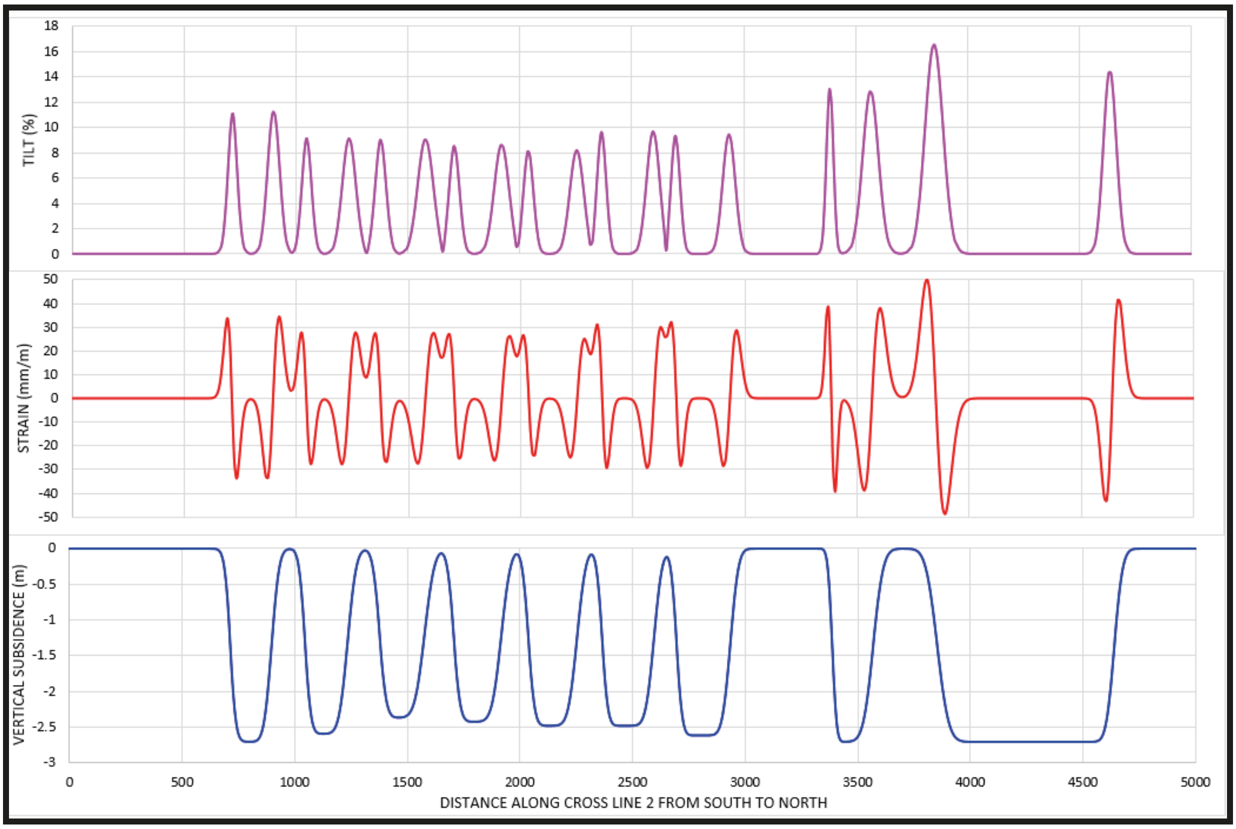

Figure 27. Subsidence, Strain and Tilt along Cross Line 2.

4.3 Limitations of the Subsidence Predictions

The subsidence predictions represent final subsidence values after longwall mining is completed. The nature of the longwall mining method means that subsidence does not increase further over time. Based on subsidence monitoring in the neighbouring Bowen Basin, greater than 97% of the maximum subsidence at a point on the surface typically occurs within 6 weeks after longwall mining has retreated past this point, assuming an industry average retreat rate of 100 m/week.

Based on the available data for the proposed longwall mining areas, there are no localised features or variations in the geology, geotechnical conditions or surface topography that are considered likely to result in any significant deviations from the subsidence predictions presented in this report.

As is good engineering practice, a review of the predictions should be conducted as any new geological/geotechnical data and subsidence monitoring becomes available. This is particularly relevant to the extraction of the A Seam above D Seam longwall panels, due to the limited availability of empirical data for dual seam extraction.

Overall, the subsidence predictions are based on well established methodologies that have been proven to provide reliable predictions at numerous similar mining operations. In any areas of uncertainty, conservative assumptions have been applied. The predictions are therefore considered suitable for assessing the potential significant impacts of subsidence on the environment.

5 SUBSIDENCE EFFECTS

The previous section has documented the predicted surface subsidence associated with the proposed longwall mining. This section provides an assessment of the effects that subsidence may have on both the overburden rock mass and the surface.

5.1 Surface Deformations

An indication of the range of predicted subsidence deformations associated with the proposed longwall mining is shown in the cumulative frequency curves in **Figure 28 and Figure 29**.

After the extraction of both the A and D Seams, 95% of the strains will be less than 20 mm/m. 80% of the tilts will be less than 50 mm/m, which is equivalent to a change in slope of 2.9 degrees.

For the C Seam extraction 70% of the tilts will be less than 50 mm/m (**Figure 29**). Most of the strains (90%) are less than 30 mm/m.

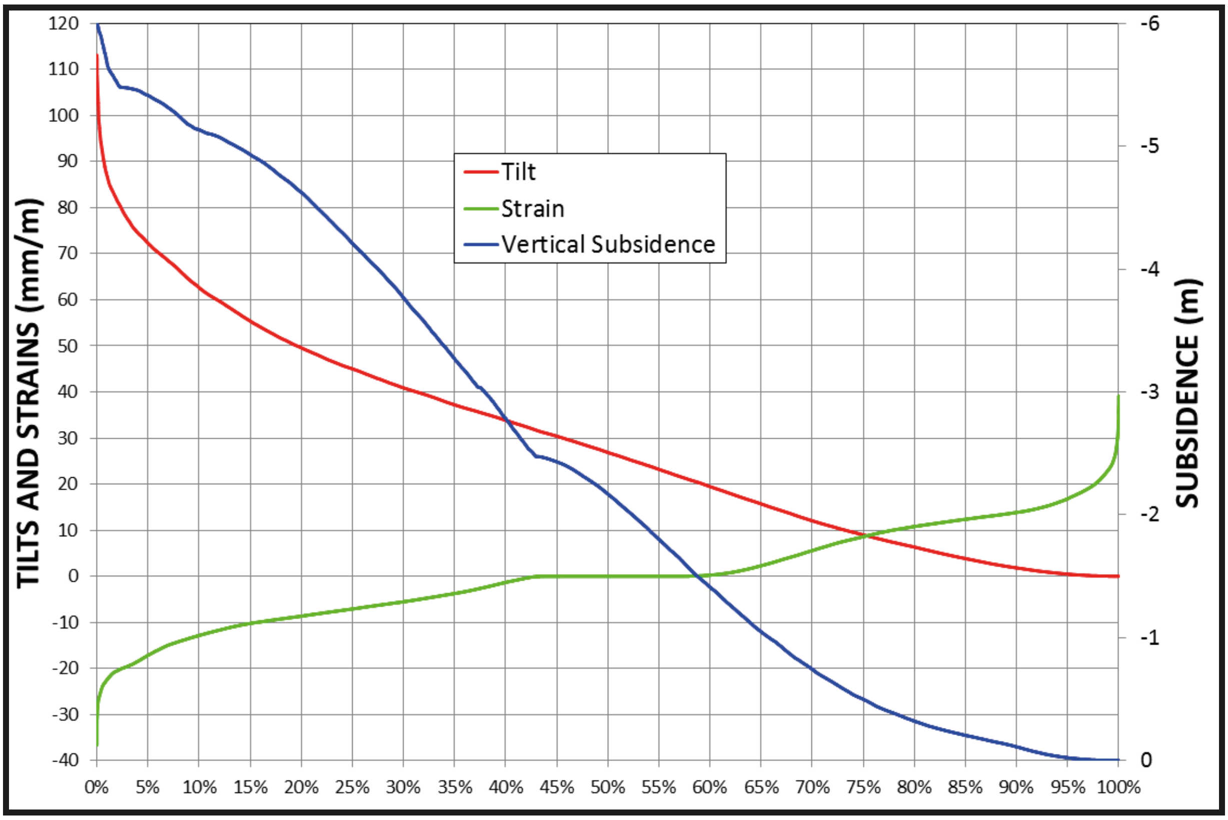

Figure 28. Cumulative Frequency Curves after Extraction of both the A and D Seams.

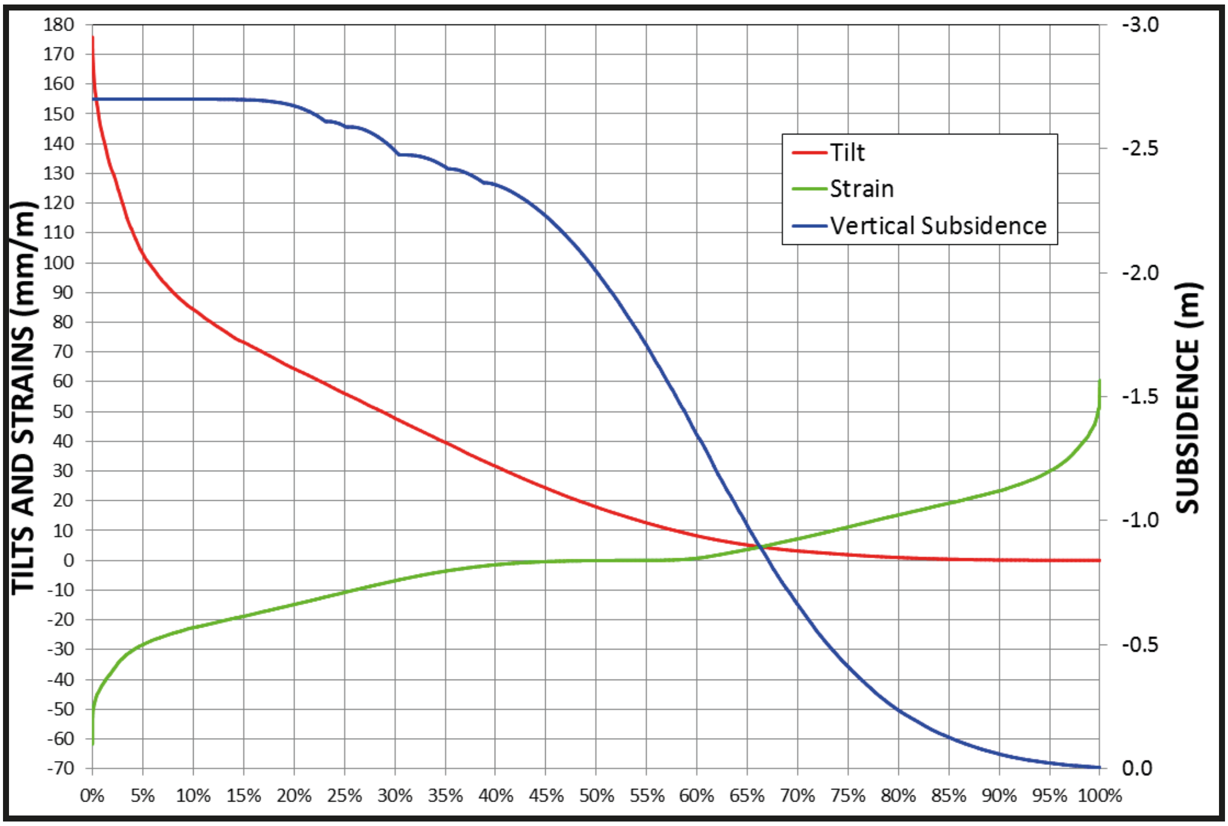

Figure 29. Cumulative Frequency Curves after Extraction of C Seam.

5.2 Subsurface Subsidence Cracking

5.2.1 Background to Subsurface Subsidence Cracking

Longwall mining methods can induce a range of subsurface subsidence effects. In the context of changes to the hydrogeological regime, the key issue associated with longwall subsidence is the creation of subsurface subsidence cracks in the rock mass. These cracks may provide new flow paths for groundwater and alter the permeability of the strata overlying longwall mining areas. The potential changes in the hydrogeological characteristics of the rock mass are dependent upon a number of variables that may affect the behaviour of subsurface subsidence cracking, such as:

- Mine geometry;
- Extracted seam thickness;
- Thickness and geomechanical properties of the overburden;
- Presence of tuffaceous horizons that may restrict the vertical flow of groundwater; and
- The bulking and compaction of the goaf material.

For operating longwall mines, it is possible to measure key subsurface subsidence cracking characteristics including the height of cracking above the extracted coal seam. This information can be correlated to measured changes in the water regime, for example decreases in groundwater levels in boreholes or inflows to underground mining areas. This provides accurate site-specific data on the known characteristics and impacts of subsurface subsidence cracking within the geological sequence.

A range of different methodologies are used to determine the heights of subsurface subsidence cracking associated with existing mining operations, such as:

- borehole extensometers;
- piezometer records;
- drilling records;
- comparison of permeability testing; and
- microseismic monitoring.

5.2.2 Prediction of Subsurface Subsidence Cracking Effects due to Single Seam Extraction

The prediction of subsurface subsidence cracking for single seam extraction has been extensively studied using both empirical and numerical modelling methods.

Models based upon empirical evidence such as observation and measurement are commonly used to predict the effects of subsidence. Empirical hydrogeological models for subsided strata are typically based on the interpretation of water inflow events.

The most commonly cited empirical model developed for predicting subsurface subsidence cracking effects on groundwater and surface water is the Bai and Kendorski (1995)[7] model (**Figure 30**). The key principle of this model is that subsurface subsidence cracking can be characterised by the following zones:

- Constrained zone – unaffected by subsurface subsidence cracking.
- Dilated (or discontinuous cracking) zone – no changes in vertical permeability, possible changes in horizontal permeability and storativity.
- Fractured (or continuous cracking) zone – changes in vertical and horizontal permeability are possible.

In this model, cracking within the dilated (or discontinuous cracking) zone is dominantly horizontal, with negligible vertical cracks. In this zone, there may be an increase in horizontal permeability but this is not likely to result in significant inflows to the underground mine workings. The fractured zone nomenclature is related to the zone of vertical hydraulic connectivity (or unrestricted inflow) and does not imply the limit of all cracking.

[7] Bai, M, and Kendorski F.S. (1995). Chinese and North American high extraction underground coal mining strata behaviour and water protection experience and guidelines. 14th Conference on Ground Control in Mining. 209-217.

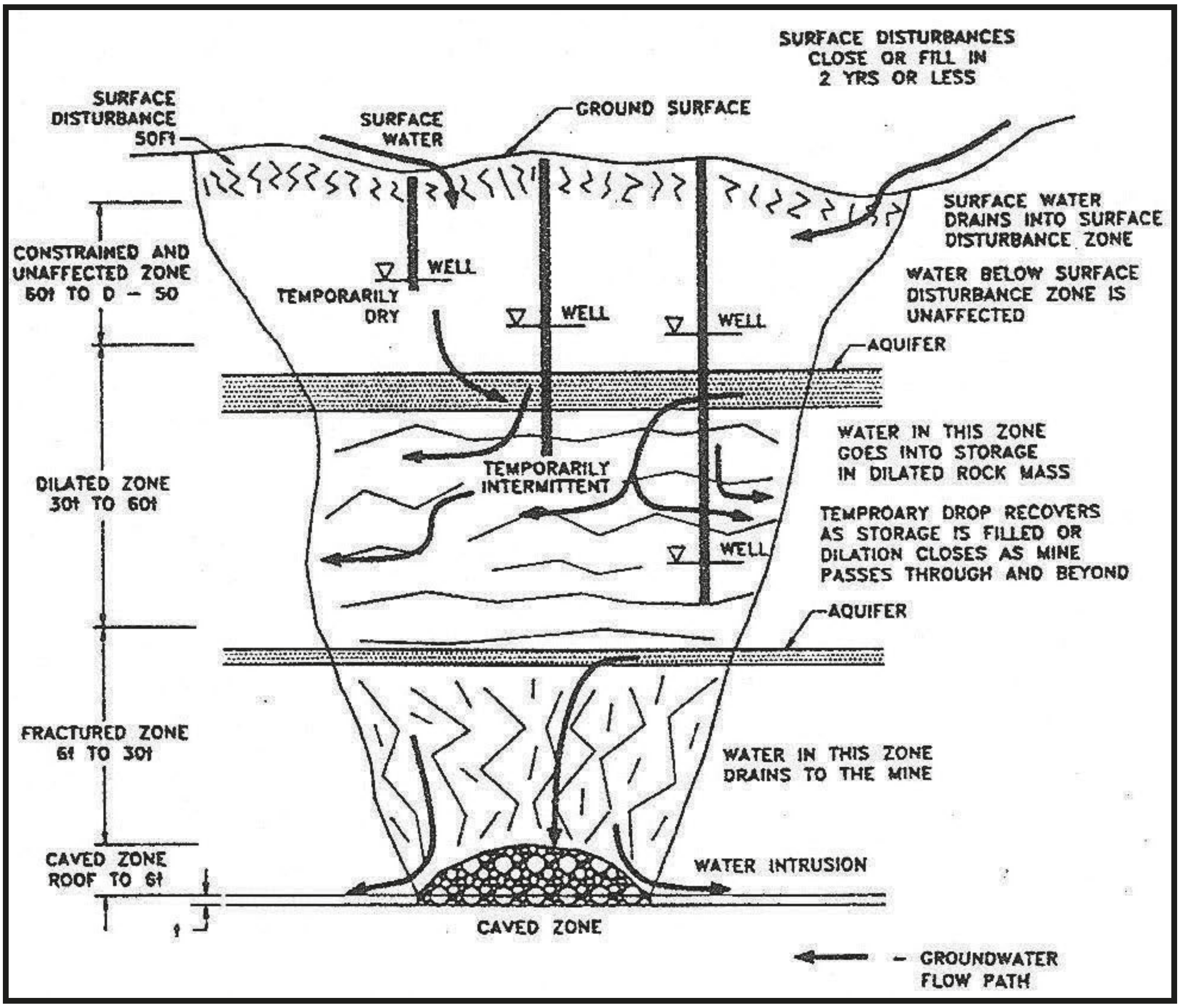

Figure 30. Hydrogeological Model for Cracking above Longwalls (Bai & Kendorski, 1995).

This model concludes that water will enter an underground mine or be lost from an aquifer or surface water body if:

- the zone of continuous subsurface cracking intersects the water body, or
- there is a connection between the continuous subsurface cracking zone and any surface subsidence cracking.

The heights of subsurface subsidence cracking in models such as that of Bai and Kendorski are related to extracted coal thickness. In **Figure 30**, the fractured zone is shown to range from 6 to 30 times the extracted seam thickness.

Alternative models are available which relate the height of continuous cracking to the mining induced tensile strains and depths of cover. However, the overall concept of dividing the rock mass into different cracking zones is common to all methods and is a well-established and valid approach to explain the measured differences in field observations arising from subsurface subsidence cracking.

Measured data taken from comparable mining operations in equivalent geology can also be used to assist with the prediction of the likely extent of each subsurface cracking zone and, in particular, the boundary between discontinuous and continuous zones of subsurface subsidence cracking.

The behaviour of the subsided rock mass can also be assessed using numerical modelling methods. Commercially available modelling software includes the Fast Lagrangian Analysis of Continua (FLAC) model.

Numerical modelling of subsurface cracking requires robust calibration, verification and validation to minimise the potential for erroneous results and requires reference to measured data. For a greenfield project with no site specific monitoring data available, a numerical model would need to be calibrated against measured data from other similar mine sites. Consequently, numerical modelling would not provide a higher level of accuracy than empirical methods in the prediction of subsurface cracking for a greenfield project, as the basis of the predictions would be essentially the same.

5.2.3 Prediction of Subsurface Subsidence Cracking Effects due to Dual Seam Extraction

GGPL is not aware of empirical studies examining the height of subsurface cracking above dual seam longwalls; however, some recent physical modelling work by Ghabraie and Ren (2014)[8] is detailed below to provide an understanding of the subsurface strata movement in a dual seam longwall mine.

Ghabraie and Ren (2014) built a physical model to investigate the mechanism of surface and subsurface movements of the strata in a dual seam longwall environment (**Figure 31**). The upper seam, located 24 m above the lower seam, was extracted first. The panel width in both seams was 120 m and the extraction height was 4.5 m. The depth of cover above the upper seam was 80 m, indicating supercritical subsidence behaviour (panel width to depth of cover ratio of 1.5).

As shown in **Figure 31**, some reworking of the upper seam goaf occurs when the lower seam is extracted. The model indicates that the height of cracking above the upper seam is increased once both seams are extracted. It is noted that additional cracking was not observed outside the previously caved zone. A conceptual model for this reworking of the upper seam goaf is shown in **Figure 32**.

In the Northern Underground the extraction sequence is reversed, with the lower D Seam extracted before the upper A Seam. The interburden between the seams is 50-70 m, which is also greater than modelled by Ghabraie and Ren (2014). The implication of this geometry is that the amount of strata in the fractured zone above the A Seam would be expected to be less than that shown in the physical model in **Figure 31**. In summary, whilst the physical model has some differences to the

[8] Ghabraie, B and Ren, G. (2014). Investigating characteristics of strata movement due to multiple seam mining using a sand-plater physical model. Proceedings of the 9th Triennial Conference on Mine Subsidence.

proposed dual seam mining in the Northern Underground, it provides useful insight to the potential subsurface cracking mechanisms for dual seam mining.

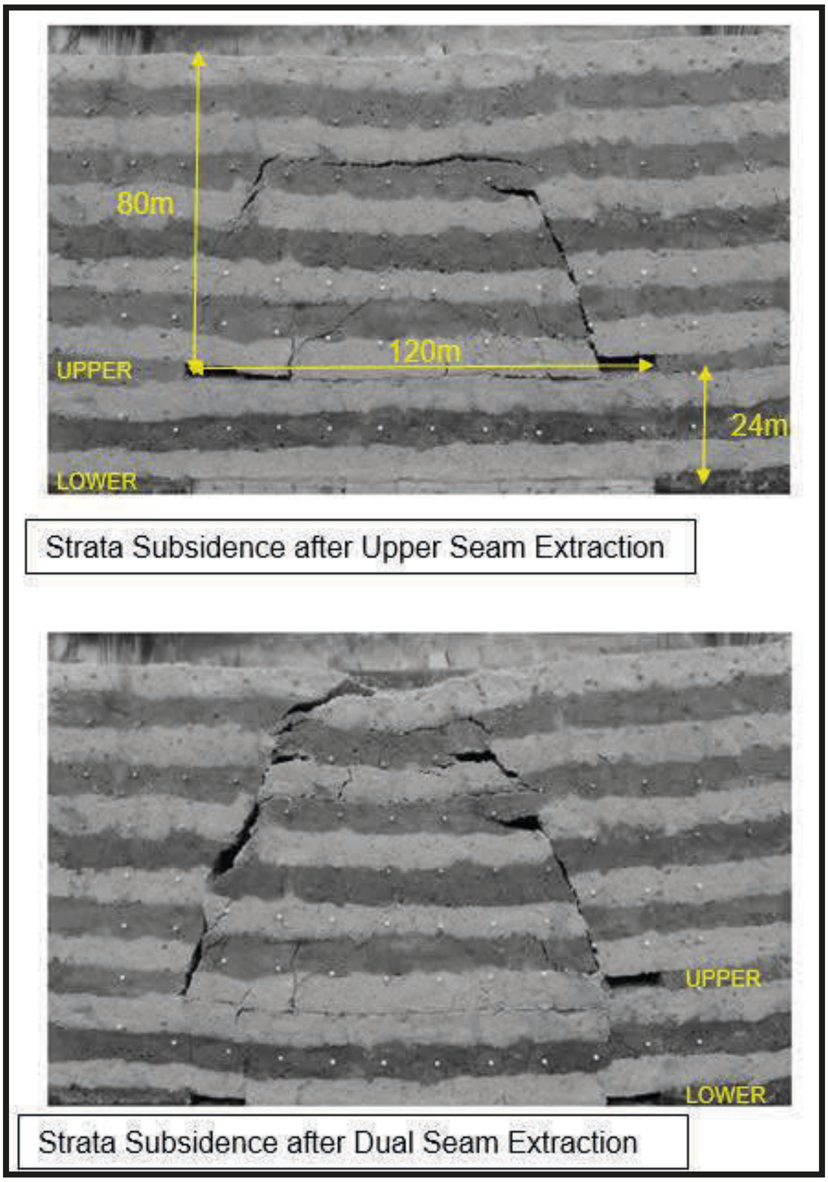

Figure 31. Results of Physical Modelling of Dual Seam Subsidence (Ghabraie and Ren, 2014).

Ghabraie and Ren (2014) found that the initial cracks formed by the extraction of the first seam could change the crack propagation above the second seam extracted. Subsidence from the extraction of the second seam opens up existing cracks and induces greater bedding separation. This is highlighted by the different displacement profiles for the two mining scenarios (**Figure 32**). The subsurface strata cracking profile after extraction of the first seam shows a balanced movement between horizontal and vertical components (**Figure 32**). In comparison, after the second seam is extracted the vertical movement is mainly restricted to a wedge shaped area, shown by dotted red line in **Figure 32**. Outside this wedge area, the horizontal displacement is the predominant displacement component.

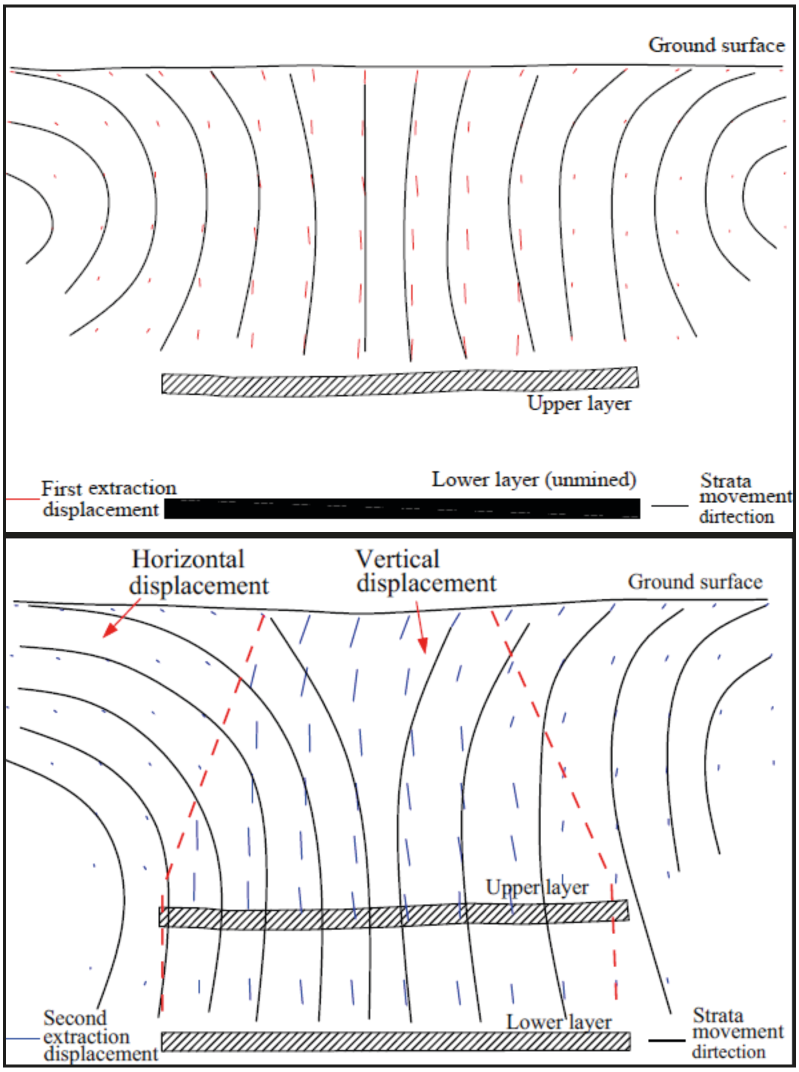

Figure 32. Displacement Profiles of Upper and Lower Seam Extraction (Ghabraie and Ren, 2014).

5.2.4 Comparative Assessment of Subsurface Subsidence Cracking Predictions for Single Seam Extraction

5.2.4.1 Water Inflow Events in the Bowen Basin

Seedsman and Dawkins (2006)[9] provide a comprehensive summary of subsurface subsidence cracking and water inflow events in the Bowen Basin.
Seedsman and Dawkins report that:

- no major surface water inflows to longwall mining areas have occurred in the Bowen Basin where the depth of cover has exceeded 120 m; and
- no major groundwater inflows to longwall mining areas have occurred in the Bowen Basin where the distance from the seam to the aquifers is more than approximately 90 m.

[9] Seedsman, R.W. and Dawkins, A. (2006). Techniques to predict and measure subsidence and its impacts on the ground water regime above shallow longwalls. ACARP Project C13009.

Klenowski (2000)[10] reports on the inflow of water at the Oaky Creek Mine and the German Creek Mining Complex in the central part of the Bowen Basin. These mines target the German Creek Coal Measures, which comprise a sequence of sandstones, siltstones, mudstones and coal seams similar to the project site.

Klenowski concluded that unrestricted inflow (i.e. from the zone of continuous cracking) generally occurs to a height of about 120 m above the active mine area. The inflow rates for different heights of cracking in the German Creek mining complex, as well as other comparable mining operations, extracting single seam longwalls, throughout the Bowen Basin, Australia and overseas, are plotted in **Figure 33**. These conclusions are consistent with the mining conditions at the Aquila mine at German Creek, where no significant cracking or slabbing of the strata was encountered in workings developed 110 m above extracted goaf.

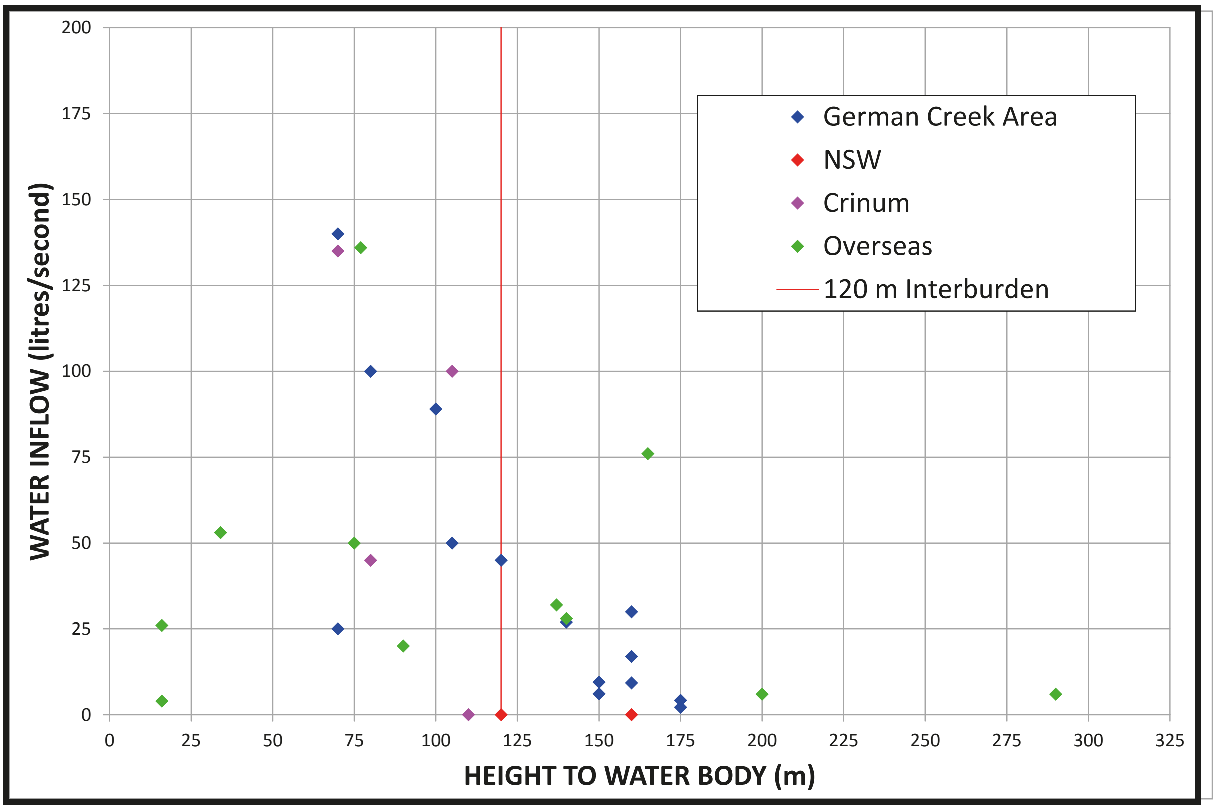

Figure 33. Summary of Water Inflow Events.

Evidence from Crinum Mine and Kestrel Mine, suggests that the presence of Tertiary clay materials in the overburden within the cracking zone may have retarded water inflow rates to underground workings (Seedsman & Dawkins (2006), Gale (2008)).

5.2.4.2 Microseismic Monitoring Data

Microseismic monitoring involves the use of geophones installed in boreholes to record the development of fractures by measuring microseismic events.

[10] Klenowski, G. (2000). The influence of cracking on longwall extraction. ACARP Project C5016.

Microseismic monitoring is one of the most reliable tools for determining the interface between continuous and discontinuous subsurface subsidence cracking. Published monitoring data is available from two Bowen Basin longwall mines.

At North Goonyella Mine, microseismic monitoring of a 250 m wide longwall panel, at approximately 150 m depth of cover was carried out. The extraction height was up to 4 m high. As shown in **Figure 34**, the majority of microseismic events occur within 120 m of the extracted seam. These results indicate the monitored limit of continuous cracking is 120 m.

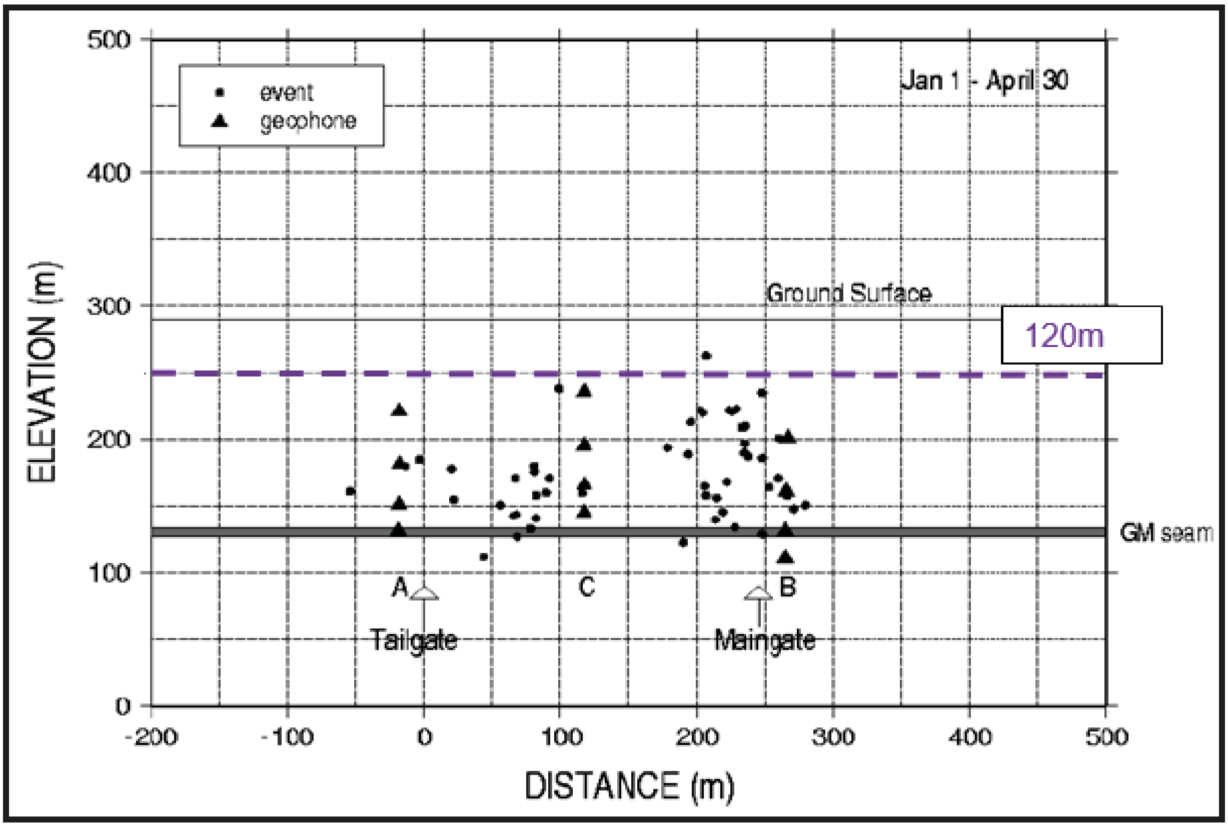

Figure 34. Location of Microseismic Events above LW3 at the North Goonyella Mine (Kelly and Gale, 1999).

Microseismic monitoring above the 200 m wide, Longwall 101 panel at Kestrel Mine indicates a marked reduction in events (i.e. cracking) at 90 m above the seam (**Figure 35**). This was taken to be the limit of monitored continuous cracking. No microseismic events were recorded higher than 115 m above the extracted seam (**Figure 35**). The depth of cover and extraction height in this area of the mine was 220 m and 3 m, respectively.

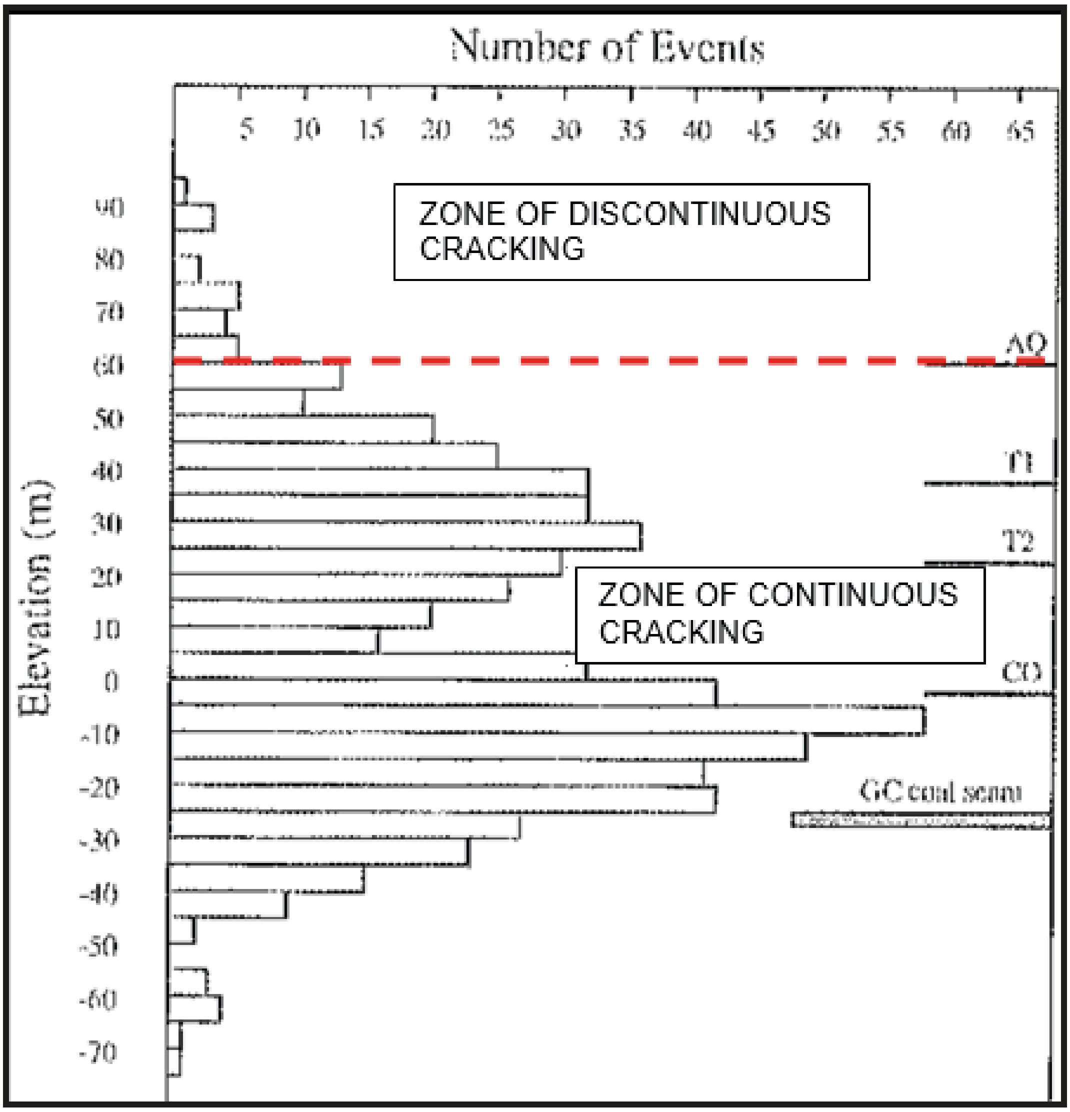

Figure 35. Location of Microseismic Events around LW101 at Kestrel Mine (Kelly and Gale, 1999[11]).

5.2.4.3 Numerical Modelling

Published numerical modelling studies by Gale (2008) in the Oaky Creek area showed a distinct decrease in the vertical conductivity to around 10^{-6} m/s, at beyond 90 to 100 m above the coal seam (**Figure 36**). This is also consistent with the field observations described above. The progressive reduction in vertical conductivity from 1 m/s close to the extracted seam, decreasing to 10^{-4} m/s at the top of continuous cracking zone is also clearly evident in **Figure 36**.

[11] Kelly, M. and Gale, W. 1999. Ground behaviour about longwall faces and its effect on mining. ACARP Project C5017.

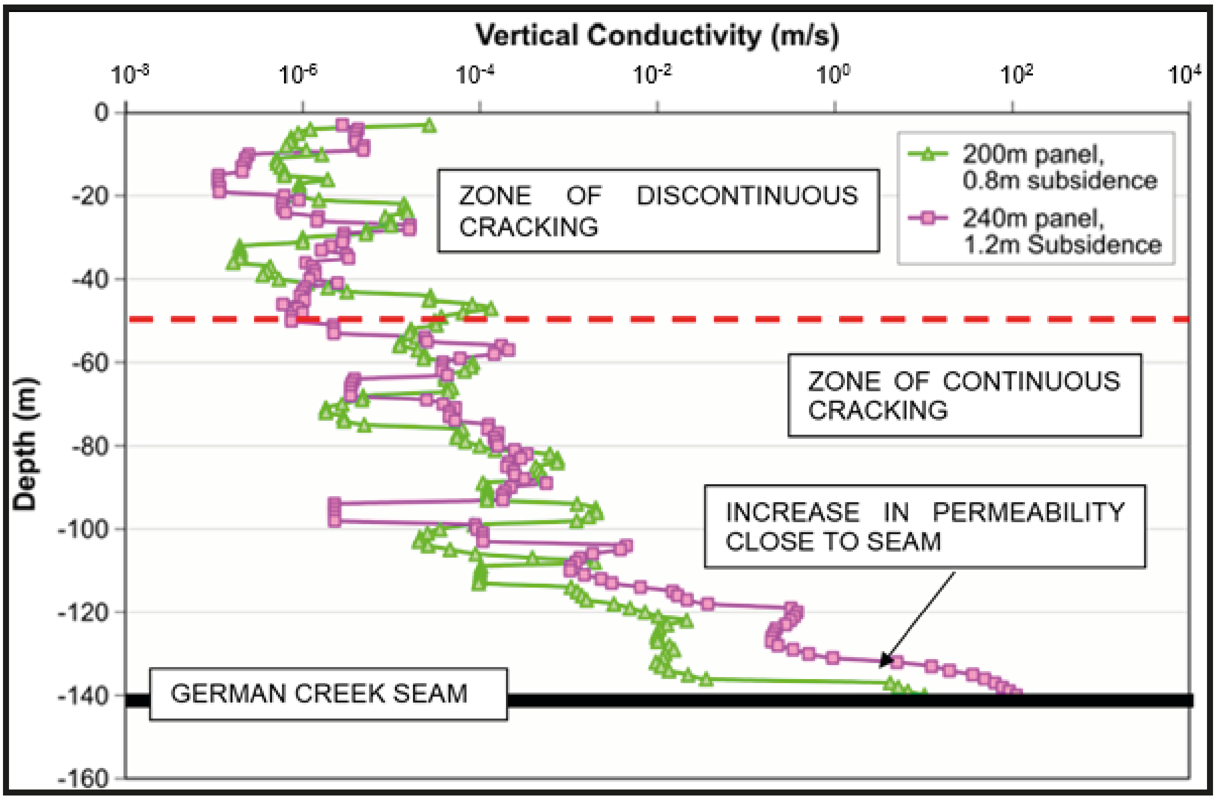

Figure 36. Vertical Conductivity through a Numerical Model in the Oaky Creek Mining Area (Gale, 2008[12]).

5.2.4.4 Summary of Data

Field observations of heights of subsurface subsidence cracking from mines in QLD, NSW and overseas are summarised in **Table 2**.

Gale (2008) also reports that 105 m of rock head is used as a standard buffer distance to minimise the risk of inflow events in the UK.

These thicknesses are consistent with monitoring conducted in NSW mines, where the potential for surface water to flow into underground longwall workings is recognised if the longwall panel is less than 100 m to 150 m below the surface.

[12] Gale, W. (2008). Aquifer inflow prediction above longwall panels. ACARP Project C13013.

Mining Area	Height of Cracking	Discussion/Evidence
Crinum, QLD	90-100 m	Height to overlying basalt/sand aquifers in the Tertiary (Seedsman and Dawkins, 2006).
NSW	100-150 m	The potential for surface water to flow into underground longwall workings is recognised if the longwall panel is less than 100 m to 150 m below the surface (Seedsman and Dawkins, 2006).
Oaky Creek and German Creek, QLD	<160 m	For ponded water at cover depths greater than 160 m, remedial works are generally not required and standard underground pumping systems are capable of handling minor increases in flow (Klenowski, 2000). Unrestricted inflow generally occurs to a height of about 120 m above the active mine area, with inflow rates progressively reducing as the depth of cover increases above 120 m (Klenowski, 2000).
Kestrel, QLD	<115 m	Microseismic monitoring of Longwall 101. (Kelly and Gale, 1999).
North Goonyella	<120 m	Microseismic monitoring of Longwall 3. (Kelly and Gale, 1999).
Wyee, NSW	40-63 m	Wide panels and strong, massive roof strata (Forster and Enever, 1992)[13].
Cooranbong, NSW	58 m	Wide panels and strong, massive roof strata (Forster and Enever, 1992).
Wistow Mine, UK	77 m	Limestone aquifer (Whittaker and Reddish, 1989)[14].
UK	<105 m of rock head	Guideline to minimise the risk of inflow (Gale, 2008).
Northern Bowen Basin	<170-250 m	Longwalls (314 m wide and 4.5 m high) successfully extracted beneath the Isaac River.

Table 2. Field Observations and Guidelines for the Height of Cracking.

5.2.5 Conclusions

The estimation of the height and behaviour of subsurface subsidence cracking is a complex issue. Specifically relating to water impacts, there is no simple calculation to estimate the height of the continuous and discontinuous zones. The estimate is further complicated by the lack of monitoring data available for dual seam longwall extraction.

Reference to measured data and site-specific experience is a means of addressing this issue for single seam extraction. For dual seam extraction the physical model studies detailed earlier have been referred to for the project site.

[13] Forster, I. and Enever, J. (1992). Hydrogeological response of overburden strata to underground mining, Central Coast, NSW. Office of Energy Sydney.
[14] Whittaker, B.N. and Reddish, D.J. (1989). Subsidence – Occurrence, Prediction and Control. Elsevier.

This approach is considered to provide a suitable basis for the assessment of the likely behaviour of subsurface subsidence for the project. With the available data, conceptual models for the subsurface subsidence effects in the project longwall areas of both single seam and dual seam extraction are discussed in the following sections.

5.2.5.1 Prediction for Single Seam Extraction

Based on the site-specific data from the Bowen Basin, including microseismic monitoring and documented unrestricted inflow events (section 5.2.4), an upper bound height of continuous cracking for single seam extraction is proposed at 120 m, as detailed in the conceptual model in **Table 3**. This is consistent with the available data from NSW and international longwall mining operations and hence provides a robust basis for the assessment of potential groundwater impacts associated with continuous cracking in single seam longwall mining areas. The empirical model of Bai and Kendorski indicates the height of cracking may be less than 120 m in areas where the D Seam extraction height is lower than 4 m (**Figure 30**).

<table>
<tr><th>Height above D Seam</th><th colspan="2">Single Seam</th></tr>
<tr><th></th><th>Description</th><th>Thickness</th></tr>
<tr><td>270</td><td rowspan="10">Constrained strata overlain by (elastic and) surface tension cracking zone.</td><td rowspan="10">NA</td></tr>
<tr><td>260</td></tr>
<tr><td>250</td></tr>
<tr><td>240</td></tr>
<tr><td>230</td></tr>
<tr><td>220</td></tr>
<tr><td>210</td></tr>
<tr><td>200</td></tr>
<tr><td>190</td></tr>
<tr><td>180</td></tr>
<tr><td>170</td><td rowspan="5">Zone of discontinuous cracking resulting predominantly in bed separations with negligible vertical cracks.</td><td rowspan="5">60m</td></tr>
<tr><td>160</td></tr>
<tr><td>150</td></tr>
<tr><td>140</td></tr>
<tr><td>130</td></tr>
<tr><td>120</td><td rowspan="11">Zone of connective cracking.</td><td rowspan="12">120m</td></tr>
<tr><td>110</td></tr>
<tr><td>100</td></tr>
<tr><td>90</td></tr>
<tr><td>80</td></tr>
<tr><td>70</td></tr>
<tr><td>60</td></tr>
<tr><td>50</td></tr>
<tr><td>40</td></tr>
<tr><td>30</td></tr>
<tr><td>20</td></tr>
<tr><td>10</td><td>Caved zone as evidenced by microseismic data and empirical models.</td></tr>
<tr><td>0</td><td colspan="2">D Seam</td></tr>
</table>

Table 3. Conceptual Model of the Subsurface Subsidence Effects at Project China Stone for Single Seam Extraction.

5.2.5.2 Prediction for Dual Seam Extraction

The conceptual model proposed for dual seam extraction is shown in **Table 4** below. This model has referenced the physical modelling studies of Ghabraie and Ren (2014) to provide a better understanding of the failure mechanisms in the overburden. Due to potential weakening of the overburden strata in the discontinuous cracking zone above the A Seam, by the extraction of the D Seam, the zone of continuous cracking is conservatively inferred to extend to 180 m above the A Seam extraction (**Table 4**).

Height above A Seam	Height above D Seam	Dual Seam	
		Thickness	Description
220	280	NA	Constrained strata overlain by (elastic and) surface tension cracking zone.
210	270		
200	260		
190	250		
180	240		
170	230	60m	Zone of discontinuous cracking due to A Seam extraction resulting predominantly in bed separations with negligible vertical cracks.
160	220		This zone may have been weakened by extraction of the D Seam and there is the possibility of some connective cracking to account for uncertainties in the failure mechanism due to dual seam extraction.
150	210		
140	200		
130	190		
120	180		
110	170	60m	Previously discontinuously cracked zone experiences reworking of existing cracks and bedding. This increases the void and eventually causes failures, resulting in failure of the upper layers (ref Section 3, Ghabraie and Ren, 2014).
100	160		
90	150		This subsidence regime mainly involves opening existing cracks with minimal generation of new cracks. This results in a similar crack propagation profile to single seam extraction. Vertical displacement due to second extraction mainly restricted to the previously disturbed zone (ref Section 4, Ghabraie and Ren, 2014).
80	140		
70	130		
60	120		
50	110	60m	Zone where existing cracks and bedding are reworked (ref Section 3, Ghabraie and Ren, 2014). Vertical displacement due to second extraction mainly restricted to the previously disturbed zone (ref Section 4, Ghabraie and Ren, 2014). Subsidence regime mainly opening existing cracks with minimal generation of new cracks.
40	100		
30	90		
20	80		
10	70		
0	60		A Seam
	50	60m	Zone of connective cracking.
	40		
	30		
	20		
	10		Caved zone as evidenced by microseismic data and empirical models.
	0		D Seam

Table 4. Conceptual Model of the Subsurface Subsidence Effects at Project China Stone for Dual Seam Extraction.

This 50% increase from the predicted continuous cracking height for single seam extraction should more than adequately account for the uncertainty associated with dual seam extraction and therefore provide a conservative basis for the purposes of assessing potential worst case groundwater impacts.

5.2.5.3 Connective Cracking to the Surface

In any areas where the depth of cover to the extracted coal seams is less than the combined height of connective cracking and surface crack depth, connective cracking to the surface could potentially occur. There are three areas above the Northern Underground and an area above the southern end of the Southern Underground where the depth of cover is less than the predicted combined maximum connective cracking heights. These areas are shown in **Figure 37**. There are no significant surface drainage lines in these areas. These areas are also close to the top of the catchment where any surface runoff is highly ephemeral. Any surface cracks that develop in these areas would be sealed during crack rehabilitation.

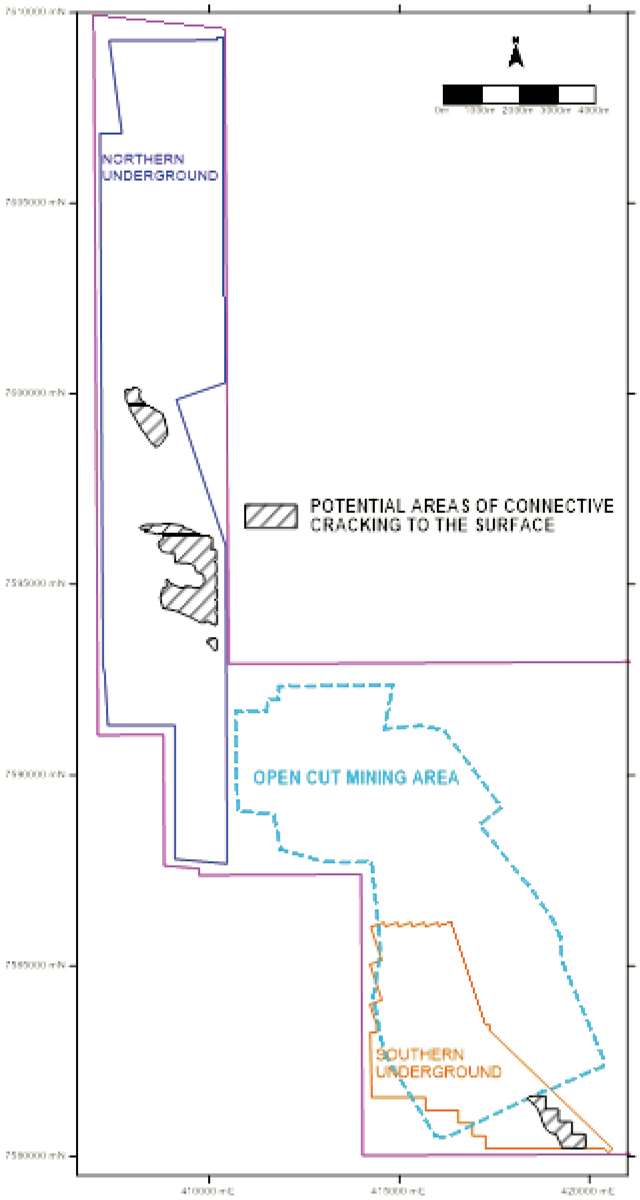

Figure 37. Areas of Potential Connective Cracking to the Surface.

5.3 Surface Cracking

5.3.1 Tension Cracks

Subsidence related cracking of the surface will develop in the proposed longwall mining areas. Whether it is discernible from the natural cracking that characterises some of the soils of the longwall mining areas will depend on the interaction between the cracks, the soil, and water. The areas with the highest potential for cracking are those located at the panel edges where the maximum tensile strain occurs.

It is noted that based on the principles of fracture mechanics, there is likely to be a direct relationship between crack width and crack depth i.e. narrow surface cracks will be shallower than wide cracks. Deeper and wider cracking could be associated with areas of high tensile strains. The widest of these cracks are predicted to extend to no more than 10-15 m below ground level based on the model of Bai and Kendorski (**Figure 30**).

5.3.1.1 Single Seam

MSEC (2007) also proposed a relationship between crack width and depth of cover with the severity and frequency of surface cracking reducing as the depth of cover increases (**Figure 38**).

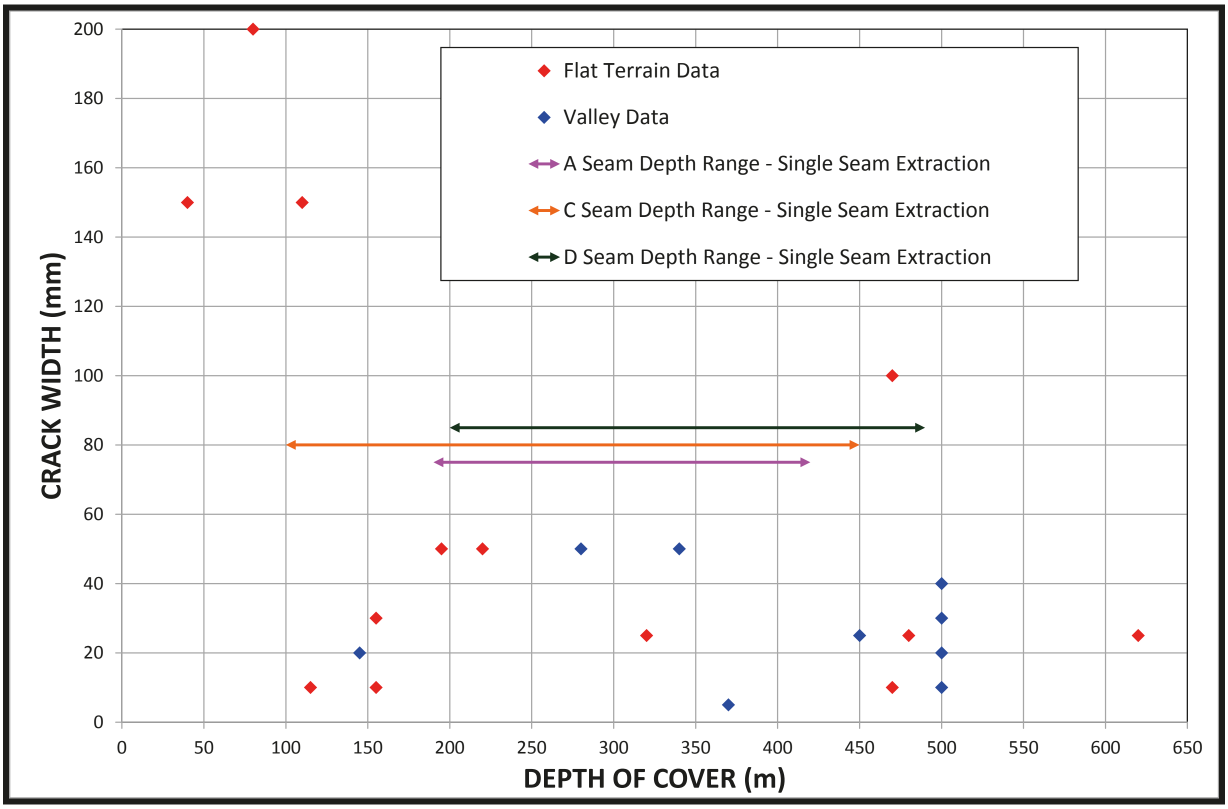

Figure 38. Crack Width vs. Depth of Cover (reproduced from MSEC, 2007).

Based on **Figure 38**, and experience at a number of operating Bowen Basin longwall mines, maximum crack widths up to 200 mm could be expected above the C Seam longwall panels in the shallower parts of the Southern Underground. The maximum crack widths predicted in single seam mining areas of the Northern Underground are 100 mm in the shallow areas, decreasing to <50 mm in the deeper areas (**Figure 38**).

5.3.1.2 Dual Seam

As well as depth of cover, ground strain is also a factor contributing to surface cracking with the largest surface crack widths predicted to occur where the strains are the highest. With reference to the predicted strains for both A and D Seam and D Seam extraction only, in **Figure 19 and Figure 21** respectively, wider cracks are expected in the dual seam extraction areas due to higher strain predictions compared to the single seam areas, at the same depth of cover.

Maximum crack widths in the shallowest areas of the dual seam section of the Northern Underground are expected to be up to 200 mm (compared to 100 mm after single seam extraction, due to the increased strains).

5.3.1.3 Type and Location of Cracks

The permanent cracks are typically located in the tensile zone around the perimeter of longwall panels. Recent surveys of permanent surface cracking at Bowen Basin longwall mines indicates that these predicted maximum subsidence crack dimensions are likely to be conservative.

Some examples of subsidence cracks from Bowen Basin longwall mines are shown **Figure 39**.

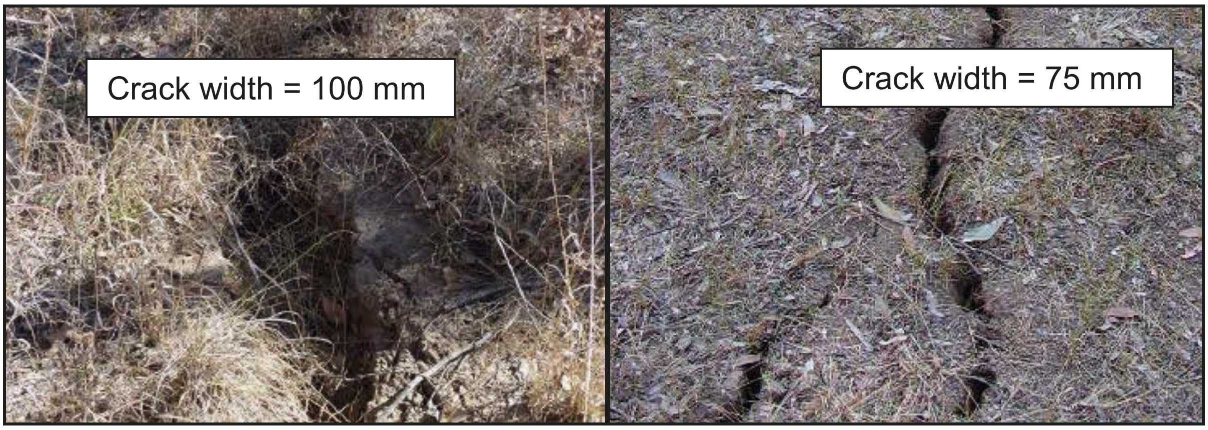

Figure 39. Examples of Subsidence Cracks.

5.3.2 Buckling and Heaving

When the near-surface strata break, the resulting blocks of rock interact and can produce localised movements. As well as surface cracking, other subsidence effects include buckling and heaving as shown in **Figure 40**.

These types of effects tend to occur less frequently than tension cracks and occur more commonly within the centre of the longwall panel area, rather than around the perimeter.

Figure 40. Heaving and Buckling.

5.4 Surface Drainage Effects

Subsidence can result in the formation of localised depressions in the surface topography that can cause ponding of surface drainage (**Figure 41**). The post-subsidence surface topography has been used to assess the potential for ponding in the EIS Surface Water Section.

Figure 41. Water Ponding over a Longwall Panel.

5.5 Subsidence Effects on Surface Geological Features

Surface geological features on the project site have been surveyed and categorised based on a reconnaissance helicopter inspection conducted by Hansen Bailey in July 2012 and a site inspection conducted by GGPL in July 2013. The site inspection involved mapping and categorisation of the surface geological features including documentation of the surface geology, feature dimensions, condition and state of weathering. The objective of this survey work was to ensure that suitable information was recorded to enable an assessment of the potential impacts of subsidence on surface geological features.

The surface geology above the Northern Underground is dominated by Darkies Range and associated erosional features (**Figure 42**). This range is dominantly composed of the Triassic Clematis Sandstone unit, which is up to 200 m thick. This unit consists predominantly of massive sandstone, with minor interbeds of siltstone and claystone.

In the low lying, flatter area to the east of Darkies Range the surface geology is dominated by Tertiary and Quaternary sediments (**Figure 43**). Localised thin pockets of Tertiary cover, <20 m thick, are also found in depressed sections on top of Darkies Range. The Tertiary in the project area consists of unconsolidated claystone and fine to medium grained weakly indurated sandstone. On the eastern side of Darkies Range, the Rewan Formation also outcrops in areas of flatter topography.

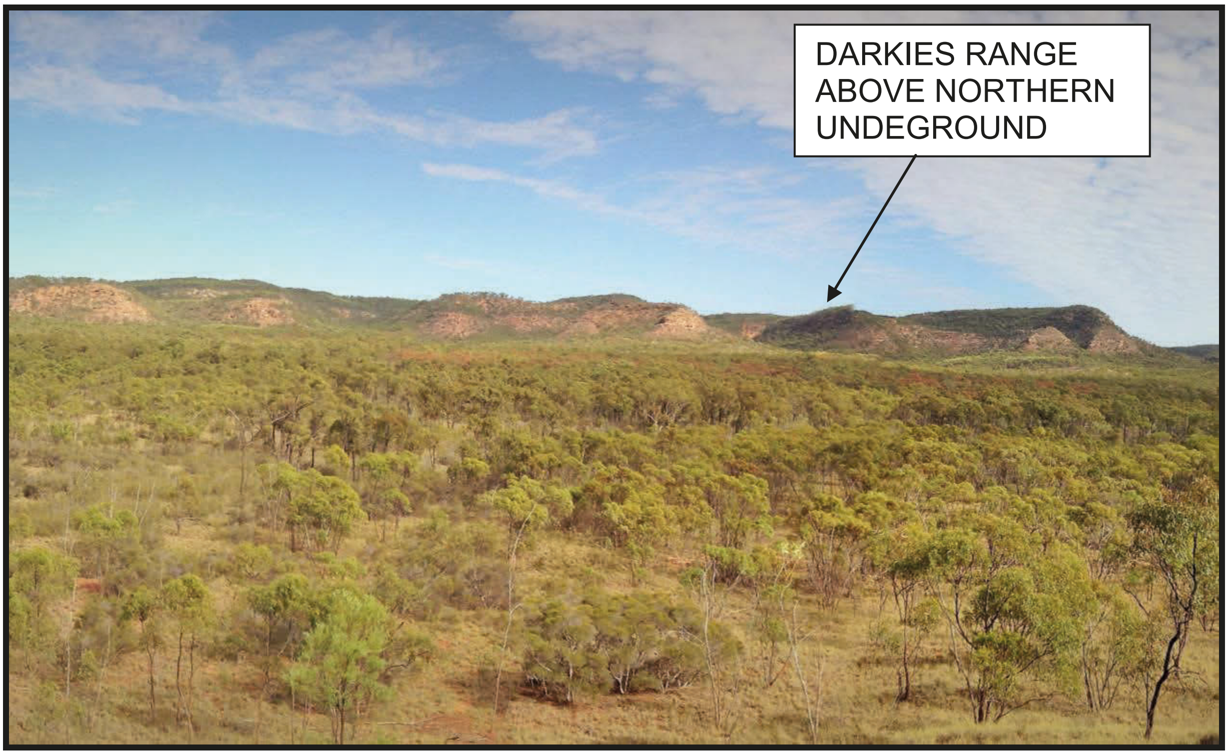

Figure 42. Darkies Range – July 2013 (Looking west).

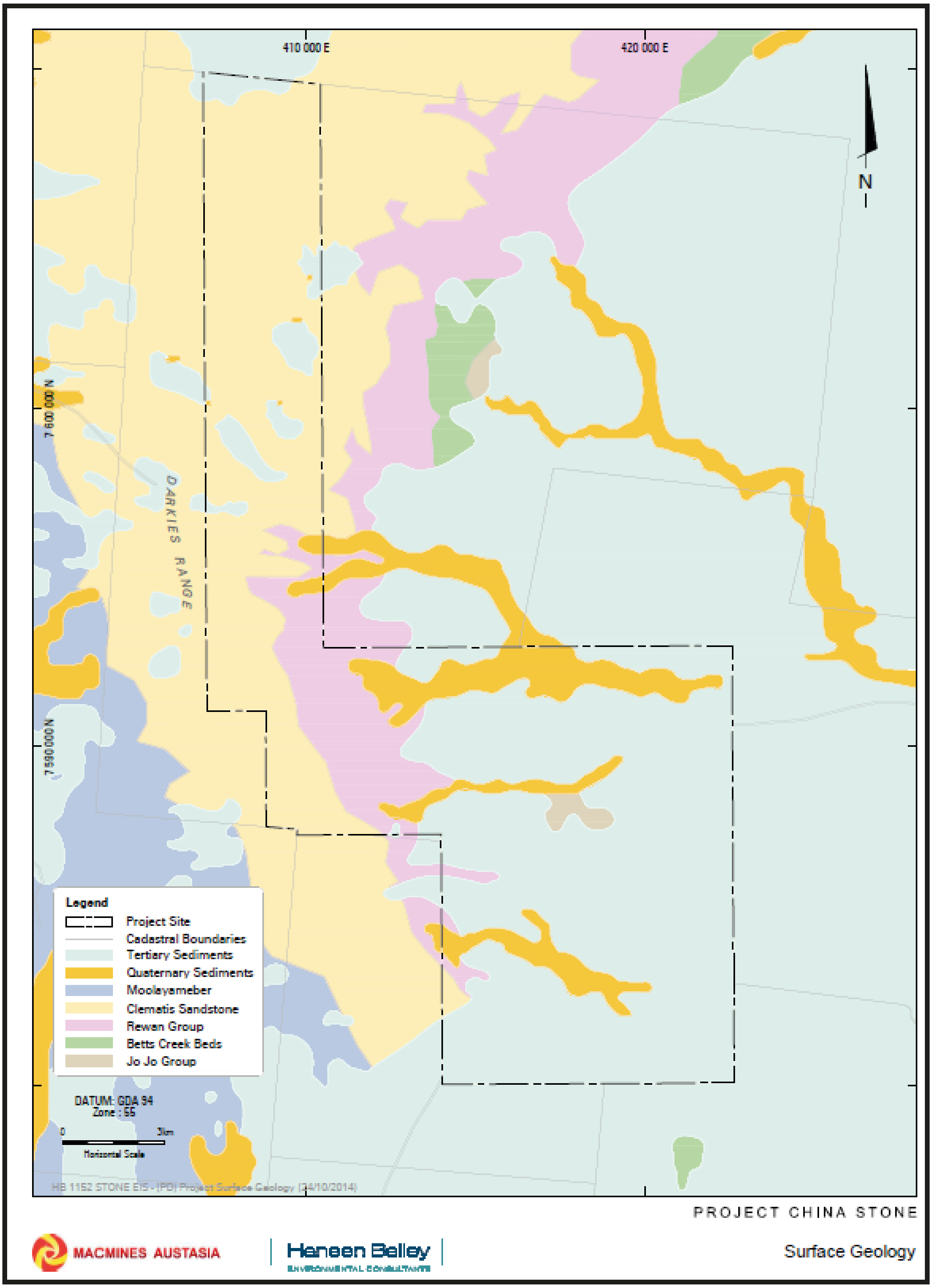

Figure 43. Surface Geology.

A range of surface features were identified including jump ups, cliffs and overhangs (**Figure 44**) and these are detailed in the following sections. As well as photographic records, field measurement of the geological joint orientations associated with features identified was also carried out. The field survey confirmed that the surface geological features on the project site are generally actively eroding due to natural weathering processes.

Figure 44. Surface Geological Features – July 2012.

The ground survey locations at which field observations were made are shown in **Figure 45** as black crosses. In addition, the photographs included in the following section to document the types of geological features are also labelled on this figure. Finally, the indicative location of the main geological features in relation to the A Seam longwall layout are identified (**Figure 45**).

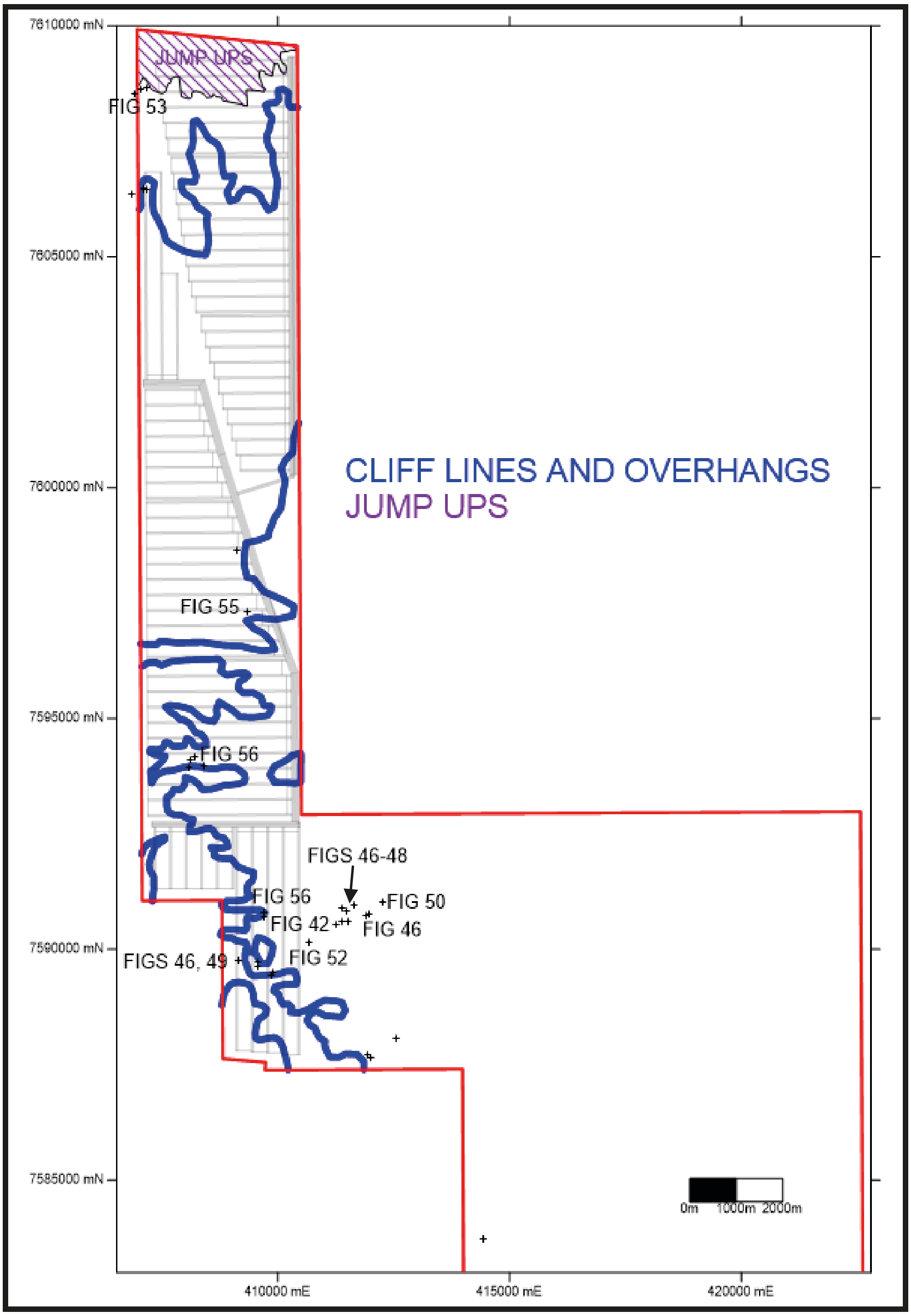

Figure 45. Location of Surface Features and Field Observation Sites.

5.5.1 Weathering Features and Failure Mechanisms

Several weathering features were noted in the outcrops around the project site in both the Tertiary, as well as the Triassic Rewan and Clematis Sandstone units. The main type of weathering appears to be the formation of overhangs due to the erosion of weaker layers (**Figure 46**). This type of weathering was noted in both the Triassic and Tertiary units.

Figure 46. Erosion of Weaker Layers.

A unique geological feature is formed in the Tertiary sediments where the less resistant material is eroded, leaving columns of more resistant rock (**Figure 47**).

Figure 47. Resistant Columns of Tertiary Strata.

Another style of weathering feature observed could best be termed an "onion" type of weathering, whereby the outer layer of sandstone weathers and peels off (**Figure 48**).

Figure 48. "Onion" Style of Weathering of Sandstone Outcrops.

The influence of jointing in the failure of large blocks was also evident in some areas (**Figure 49**).

Figure 49. Failure of Clematis Sandstone along a Joint Plane.

Natural rock falls were observed in a number of areas where an overhang has collapsed (**Figure 50**). In the extreme case, a large sandstone boulder, which had dislodged from the cliff line at the top of the range, was observed to have formed overhangs in-situ (**Figure 51**).

Figure 50. Natural Rock Falls.

Figure 51. "Mushroom" Sandstone Rock Fall Feature.

Hard ironstone bands were identified within in the Tertiary deposits (**Figure 52**). These layers form a "capping" which may reduce the weathering processes in these outcrop areas.

Figure 52. Ironstone Capping over a Sandstone Layer.

5.5.2 Feature 1 – Jump Up in the Clematis Sandstone

Where the Clematis Sandstone is exposed in the high plateau area in the northern part of the project site, distinct surface landforms were evident (**Figure 53**). This area is collectively called a jump up.

Figure 53. Jump Ups in the Clematis Sandstone.

5.5.3 Feature 2 – Overhangs

As detailed earlier, preferential weathering and erosion of softer layers forms overhangs. It should be highlighted that these overhangs are not caves and the active weathering process results in progressive collapse of overhanging rocks preventing cave formation.

These features are formed in both the Tertiary and Triassic units. Due to the strength of the strata, the overhangs typically span less than 5 m. The crumbly and bedded nature of the sandstone units, as well as the occurrence of jointing, assists the weathering process (**Figure 54**).

Figure 54. Jointing and Bedding in Sandstone.

5.5.4 Feature 3 – Cliffs

Cliff lines were observed both in the Tertiary and Triassic sediments. The maximum heights of the cliffs in Tertiary strata are in the range of 10-15 m (**Figure 55**).

Figure 55. Cliff Lines in Tertiary Strata.

The Triassic sandstone cliffs are slightly higher, with an estimated maximum height of 20 m (**Figure 56**).

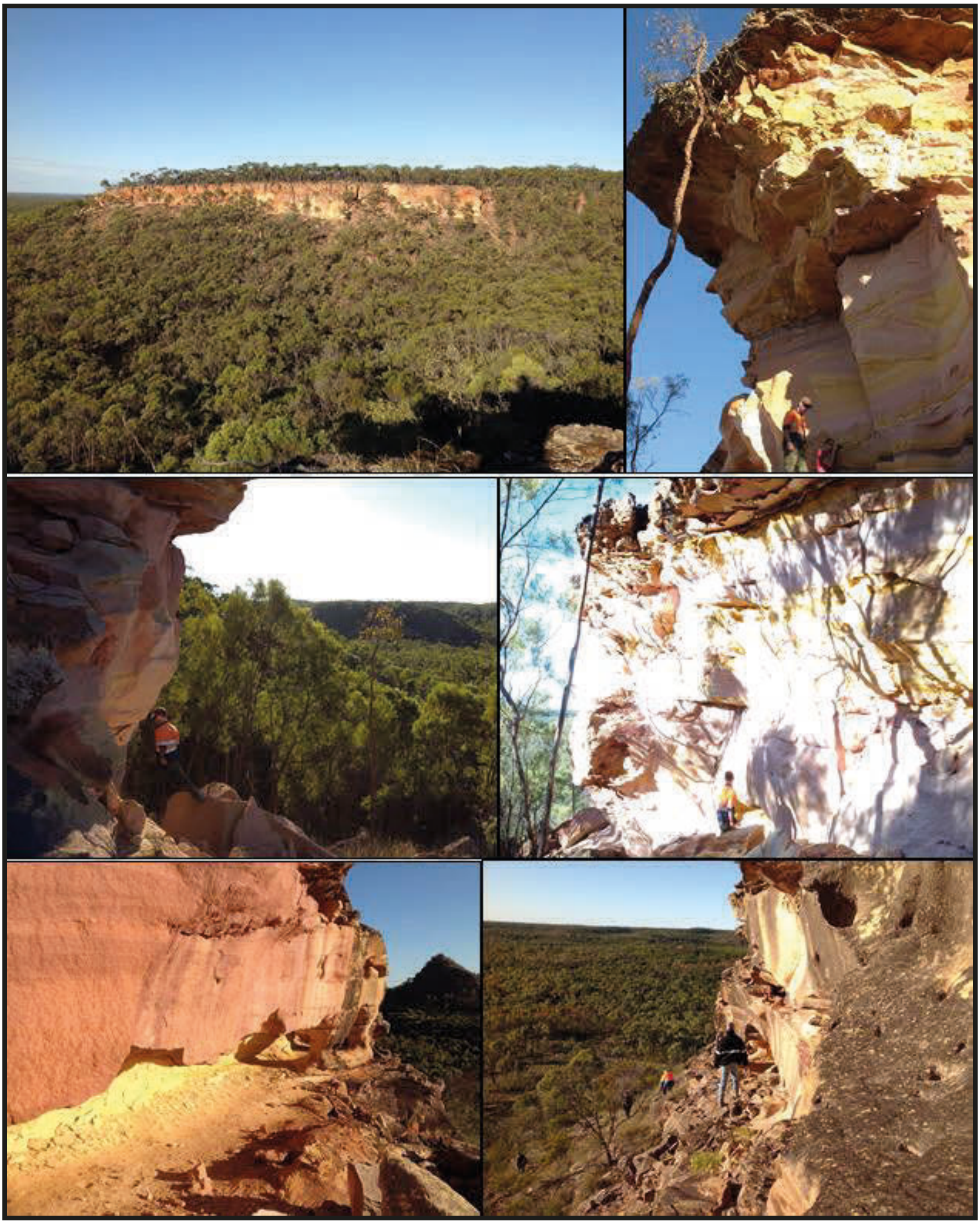

Figure 56. Sandstone Cliffs.

5.5.5 Subsidence Effects on Surface Geological Features

Experience in the Western Coalfield of NSW has found that mining directly under high sandstone cliff formations results in rock falls of varying severity. The severity is largely due to the geological and topographical structure of the overlying rock and the severity of the subsidence movements (Radloff and Mills, 2001[15]).

Radloff and Mills identified that in the Western Coalfield of NSW the visual impact is significantly reduced within 10 years of mining and many smaller rock falls are no longer visible. It should be highlighted that the cliff lines in this coalfield are larger and more topographically significant than the surface features in the project site (**Figure 57**).

Figure 57. Cliff Line – Western Coalfield, NSW (Radloff and Mills, 2001).

Other significant findings by Radloff and Mills include:

- Typically less than 20% of cliffs within the mined area experience rock falls.
- Most rock falls occur over the mined area.
- Natural rock falls have been occurring for hundreds of thousands of years as part of the natural weathering process.

[15] Radloff, B.J. and Mills, K.W. (2001). Management of Mine Subsidence Impacts on Cliffs at Baal Bone Colliery (Western Coalfields NSW). Proceedings of the 5th Triennial Conference of Mine Subsidence, August 2001. Pp. 63-76.

A similar study by Shepherd and Sefton (2001[16]) in the Southern Coalfield of NSW also found that longwall mining below 52 rock shelters resulted in visual damage to only 5 of the shelters (<10%).

Data presented in AusIMM (2009) indicates that at overburden depths of 100 to 200 m up to an average of about 16% of cliffs undermined by longwalls are observed to experience rock falls. At depths of 500 m, this percentage reduces to <2%.

The significance rating matrix developed by Radloff and Mills is useful for determining the likely subsidence impact due to longwall mining subsidence. This matrix considers a number of factors including:

1. Physical characteristics such as cliff height and length.
2. Geological and mining characteristics such as joints, geological structure, position relative to the longwall, and the panel width/depth ratio.
3. Association with environmental features and
4. Human use aesthetics.

These factors have been considered in determining the potential effects of longwall mining on the surface features in the project site. In areas where longwall mining is not carried out the weathering processes will continue to actively erode the surface features. In the shallower longwall mining areas, it is expected that some effects may be experienced on <20% of the surface features based on monitoring in NSW. The percentage of features effected is expected to decrease in the deeper mining areas. These effects are considered an acceleration of the natural erosion process.

6 CONCLUSIONS

The key conclusions from this report include:

1. Vertical subsidence reaches a maximum of 6 m in the shallower panels in the western part of the dual seam mining area of the Northern Underground and is often >5 m. In the deeper parts of the area, the maximum subsidence reduces to 4 m. In the Southern Underground the maximum vertical subsidence is 2.7 m. Far field subsidence effects are not considered significant on the surface due to the topography of the project site.

2. The maximum tensile strains due to dual seam extraction in the Northern Underground range in magnitude up to 36 mm/m. Maximum compressive strains range up to 31 mm/m. 95% of the strains due to dual seam extraction in the Northern Underground will be less than 20 mm/m.

3. The maximum tilts developed due to dual seam extraction in the Northern Underground range up to 11% or 110 mm/m in the shallower 400 Series area. 80% of the tilts across the area will be less than 50 mm/m, which is equivalent

[16] Shepherd, J. and Sefton, C.E. (2001). Subsidence Impacts on Sandstone Cliff Rock Shelters in the Southern Coalfield NSW). Proceedings of the 5th Triennial Conference of Mine Subsidence, August 2001. Pp. 77-85.

to a change in slope of 2.9 degrees. Higher tilts can be expected in the shallowest Southern Underground C Seam extraction areas.

4. Based on subsidence monitoring at Bowen Basin longwall mines in similar geology, greater than 97% of the maximum subsidence will typically occur within 6 weeks after longwall mining is completed, assuming an industry average retreat rate of 100 m/week.

5. There is confidence in the subsidence predictions due to the amount of information available from more than 25 years of underground mining experience in the neighbouring Bowen Basin mining area. This data has provided a sound basis to enable conservative prediction of potential environmental impacts due to subsidence effects. It is considered unlikely that there will be any significant deviations from the current predictions due to topographic, geological or geotechnical variations.

6. Based on experience in Australia and overseas, continuous subsurface subsidence cracking and resultant unrestricted inflow generally occurs to a height of about 120 m above the active longwall in single seam extraction areas, with inflow rates progressively reducing as the depth of cover increases above 120 m. As such, continuous cracking up to 120 m above the longwall panels extracted in virgin ground can be expected.

7. In the dual seam mining areas in the Northern Underground, a more conservative height of 180 m for continuous cracking above the A Seam longwall should be assumed. This 50 % increase from the initial predicted continuous cracking height should more than adequately account for the uncertainty associated with the continuous cracking height predictions and therefore provide a conservative basis for the purposes of assessing potential worst case groundwater impacts.

8. Surface subsidence cracks will develop in the proposed longwall mining areas. The areas with the highest potential for cracking are those located at the panel edges where the maximum tensile strain occurs. The widest of these cracks are predicted to extend to no more than 10-15 m below ground level. Maximum surface crack widths up to 200 mm could be expected above dual seam extraction areas of the Northern Underground and the shallower parts of the Southern Underground mining area. At greater depths, maximum crack widths <50 mm could be expected. Cracks of this size can be readily remediated.

9. In areas where longwall mining is not carried out the weathering processes will continue to actively erode the surface geological features. In the shallower longwall mining areas, it is expected that some effects may be experienced on <20% of the surface features based on monitoring in NSW. The percentage of features effected is expected to decrease in the deeper mining areas. These effects are considered an acceleration of the natural erosion process.